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Simulation Roadmap for Program Executive Office (PEO) Soldier

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14. ABSTRACT
Maintaining an edge during this time of unprecedented technological growth requires that the Army field Infantry soldier systems quickly. The risk of doing so without some assessment of utility, however, is quite high, and the acquisition community must estimate the operational impact of proposed systems with an increasing degree of accuracy. For this, the Army has turned to combat simulations. However, the representation of the individual soldier in simulations has not kept pace with other representations. We applied the systems engineering process to support the needs of the Infantry soldier system acquisition community by identifying the best path forward to utilize and/or develop simulation capabilities that meet program manager's needs. Our recommendation was that PEO Soldier pursue the enhancement of and linkage between Combat[XXI], the Infantry Warrior Simulation, and Objective One Semi-Automated Forces. In this report, we discuss the process that we applied and our results, as well as our initial plan for implementation.

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Abstract

One of the primary challenges facing the United States Army acquisition community is that of quickly fielding technologically-advanced equipment to the force. The high cost of doing so brings with it significant risk, as demonstrated by the Crusader artillery and Comanche helicopter programs, both multi-billion dollar programs cancelled within the last two years. As a result, program managers must be able to reasonably guarantee the utility of their products early in the design phase and to continue doing so throughout the product's lifecycle. To that end, the Army has turned to simulation to evaluate the combat effectiveness of its proposed systems.

Unfortunately, the development of technological capabilities, especially with respect to information sharing, is outpacing improvements in current combat simulation capabilities. Moreover, until recently, the focus of the combat modeling community has been on large battlefield platforms and unit-level analyses. As a result, the representation of the individual soldier on the battlefield has not kept pace with other representations. These Infantry soldier models require unprecedented fidelity in terms of the Infantry soldier entity and his environment. The Program Executive Office Soldier (PEO Soldier), the Army program manager for the acquisition of nearly all the items carried or worn by the Infantry soldier, requires such high-fidelity models of the Infantry soldier in order to evaluate the effectiveness of its products. They have realized that the existing simulation capability is not up to the task.

We used the Systems Engineering and Management Process (SEMP), taught at the United States Military Academy as the standard problem solving methodology, to identify PEO Soldier's requirements for an Infantry combat simulation and to recommend a path forward to them. We recommended that they pursue the modification of and linkage between three simulation software packages under development: Combat^{XXI}, the Infantry Warrior Simulation and Objective OneSAF.

Our application of standard systems engineering tools led to a unique characterization of the requirements of a simulation capability specific to Infantry soldier system acquisition. Those requirements differ in many ways from Infantry simulations developed for other purposes and often applied unsuccessfully to the project management domain. Using those requirements, we were able to describe the ideal simulation and compare current simulations to that model.

In this report, we briefly discuss the problem background and methodology. We then delineate our findings and results in detail, pointing out the unique insights obtained through the application of the systems engineering process. Finally, we conclude with our recommendation to PEO Soldier for addressing their unique project management needs and our plans for implementation.

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Our mention of contributors does not imply their approval of our results. The opinions contained herein are the opinions of the authors, and do not necessary reflect those of PEO Soldier, the United States Military Academy, the United States Army, or the Department of Defense.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction.

1.1 General.

The Army acquisition community requires high-resolution simulations that represent the dismounted Infantry soldier in enough detail to estimate the operational effectiveness of soldier weapons and equipment. Such a simulation package must be robust enough to model advanced concepts like tactics, command and control, shared situational awareness, soldier fatigue, and information overload, in addition to weapons effects, soldier functions, and terrain characteristics. It must be sensitive to technological advances in weapons, sensors, and equipment. Traditionally, simulation innovations in these areas have been a result of a capabilities-based approach in which specific capabilities have been added to existing software to satisfy a certain niche. However, we believe that the Army requires a needs-based analysis that will identify the precise simulation requirements necessary to support acquisition decision making. From there, a simulation solution can be designed to meet the Army's Infantry soldier system acquisition needs. In this report, we discuss our approach beginning with a brief description of the problem background and the methodology we used. We then delineate our findings and results in detail, pointing out the unique insights obtained through the application of the systems engineering process. Finally, we conclude with our recommendation to PEO Soldier for addressing their unique simulation needs and our plan for implementation.

1.2 Background.

1.2.1. SMART.

Over the last decade, the United States Army has emphasized the importance and utility of using simulations throughout the acquisition process. This initiative was initially called simulation-based acquisition (SBA), and is now part of the Simulation and Modeling for Acquisition, Requirements, and Training (SMART) program. The SMART program "involves rapid prototyping using M&S [modeling and simulation] media to facilitate systems engineering so that materiel systems meet users' needs in an affordable and timely manner while minimizing

risk (Army Model and Simulation Office, 2002b)." With this initiative come the challenges of identifying and developing the appropriate simulation packages for each step in the acquisition process, from concept development to lifecycle management.

1.2.2. PEO Soldier.

The Program Executive Office (PEO) Soldier faces such a challenge. The mission of PEO Soldier is "to arm and equip Soldiers to dominate the full spectrum of peace and war, now and in the future (PEO Soldier, 2003);" therefore, that organization is responsible for the acquisition of most of the weapons and equipment carried and used by the Infantry soldier. PEO Soldier has three subordinate Project Manager organizations, which are divided by the type of systems they manage. Each Project Manager is further broken down into Product Managers, who manage the acquisition of more specific equipment. See Figure 1 below.

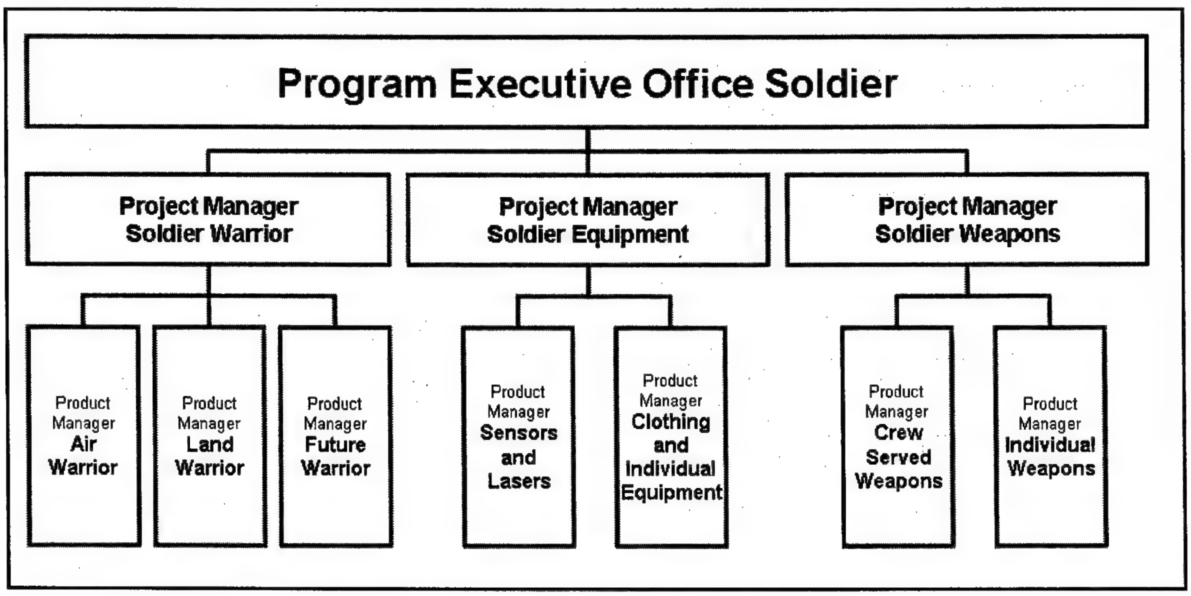

Figure 1. PEO Soldier organizational structure.

A current focus of PEO Soldier, and the focus of this study, is to identify a simulation package that will provide the means to quantify the platoon-level operational effectiveness of a new system or component as part of the SMART concept. PEO Soldier's need, as a system acquirer and integrator, is shared by materiel developers and item-level evaluators as well. Thus the identification of an appropriate simulation will have far-reaching application to organizations throughout the Army.

1.2.3. DoD Models and Simulations.

The Department of Defense (DoD) organizes its models and simulations into levels based on their degree of aggregation. Figure 2 is a diagram of the four categories of DoD models and simulations. PEO Soldier is interested in simulations that operate in the middle region – mission/battle and engagement-level models. While the military has been involved in developing simulations for many years, the emphasis was on large-scale, campaign-level models designed to represent the potential engagements of a full-scale war with the Soviet Union. Even most simulations that were able to represent the individual soldier focused on larger units and battlefield systems, often modeling the individual soldier using the same algorithms as a tank, but changing its speed, range, weapons, etc., to match soldier attributes. Now, the decentralized, networked nature of current conflicts and the multiple roles of the US soldier dictate the need for higher fidelity simulation models at the soldier level.

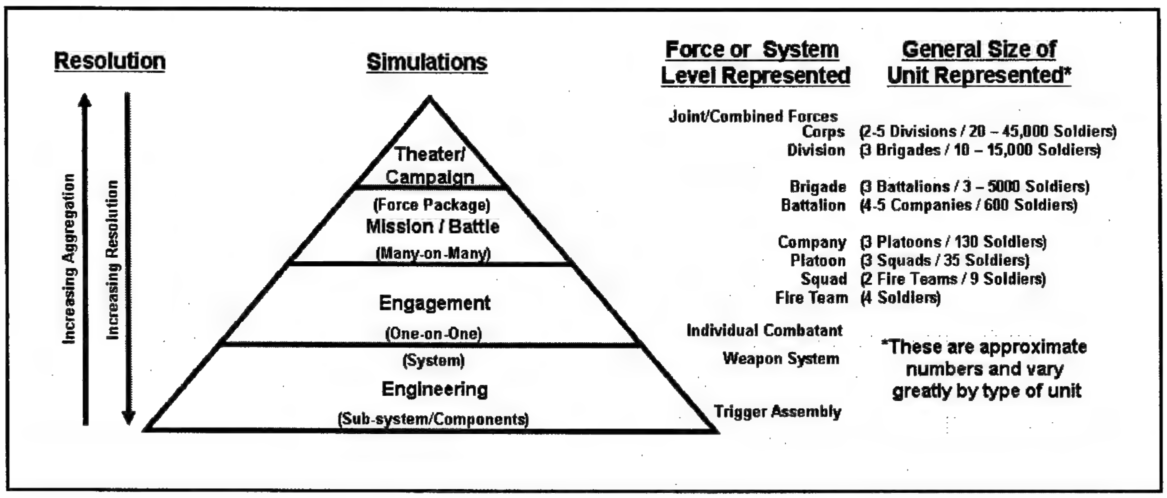

Figure 2. DoD combat model and simulation hierarchy.

1.2.4. Current Efforts.

To date, various Army agencies and contractors have recognized the need and have made considerable efforts to tackle the problem. From our observations, their efforts to identify requirements fall into two categories. The first is an upgrade-based approach, wherein the recognition of a unique requirement drives changes to an existing (legacy) simulation to meet that need. This is an iterative approach that leads to a continual upgrade cycle, often resulting in numerous concurrent versions of the same software, and is limited by the architecture and design of the software. This method is used primarily by organizations that either do not have the

funding or the time to create a new simulation, or are the primary proponents for the legacy software. For software that has the architecture to support such changes, this method can be a valid technique for meeting requirements. However, this process rarely results in a comprehensive set of requirements that fully identifies an organization's needs, a valuable product itself.

The other category is a characteristics-based approach. In this approach, an organization identifies its requirements based on the characteristics upon which the system will be evaluated. While this approach does result in a comprehensive set of requirements, it too has some drawbacks. One is that the characteristic itself may not be well-defined or translate well into simulation requirements. For instance, a commonly-used term for a capability improvement of modern soldier systems is their ability to enhance a soldier's *situational awareness*. Not only is the definition of this term not widely agreed upon, it is hard to decompose into requirements. A soldier's situational awareness directly affects, and is directly affected by, other high-level characteristics like mobility, lethality, and survivability, which themselves overlap for many of the soldier's functions. That interdependence complicates the logical decomposition into simulation requirements. Also, the terminology of the resulting product may not be easily understandable by all simulation stakeholders.

1.3 Systems Engineering and Management Process (SEMP).

We used the Systems Engineering and Management Process (SEMP), taught in the Department of Systems Engineering at the United States Military Academy (USMA) as the standard systems engineering process – shown in Figure 3. We will briefly describe the process. Overall, the SEMP is an iterative process, allowing the analyst to make refinements to any products based upon new information or discoveries regardless of where in the process the information is discovered.

The first phase is Problem Definition, consisting of Needs Analysis and Value System Design. The Needs Analysis begins with an initial problem statement from the client. With that, the analyst utilizes various tools and techniques to convert that initial problem statement into a revised problem statement that fully encapsulates the client's true need. The four main techniques used in this step are 1) a full decomposition of the system under study into its subsystems and components; 2) a review of literature and related research; 3) a stakeholder

analysis; and, 4) a functional decomposition of the system leading to requirements definition. Other important techniques include analyses of system inputs and outputs, futures analyses, and Pareto-type analyses. With an accurate revised problem statement, the study moves into the second step of Problem Definition – Value System Design. Here, the engineer uses value-focused thinking to transform the required functions of the system into objectives and measures to evaluate those objectives. The resulting value system represents the values of the primary stakeholders and provides a basis to evaluate future alternative solutions to the problem under study.

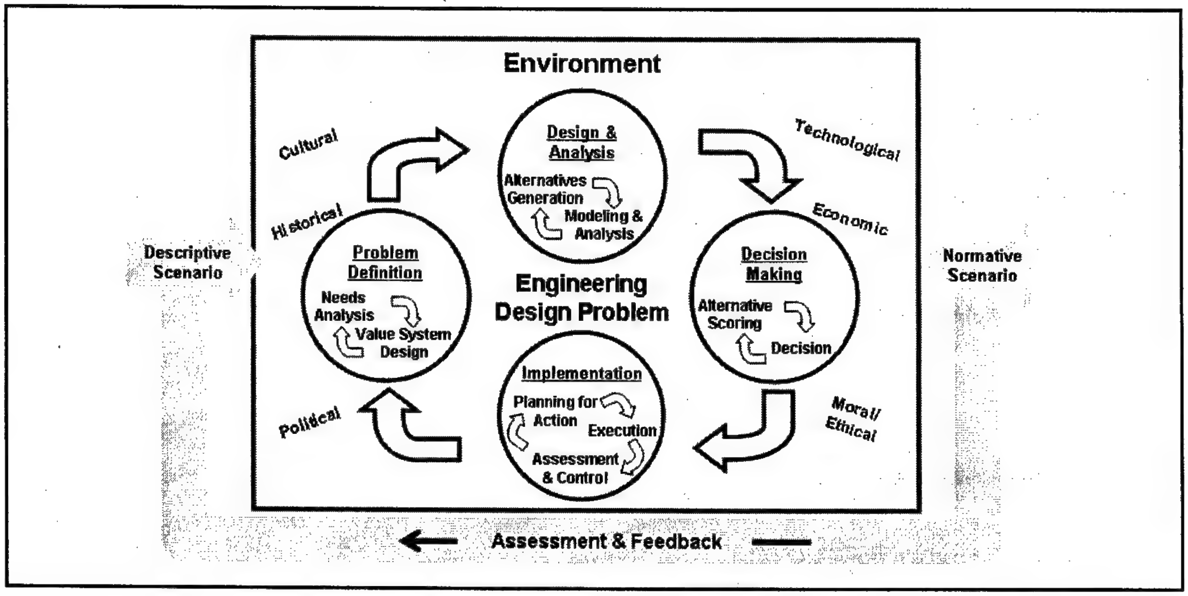

Figure 3. Systems Engineering and Management Process (McCarthy, et al., 2003).

After determining the requirements, the study moves into Phase II of the SEMP – Design and Analysis. During the first step of this phase – Alternative Generation – we generate potential alternative simulation solutions that will facilitate PEO Soldier's evaluation of selected soldier systems. During Modeling and Analysis, we analyze each alternative to determine the degree to which that alternative meets the requirements. We do that by evaluating the alternatives against the measures developed during Phase I.

Following the above analysis, we move into Phase III of the SEMP – Decision Making – and use the value hierarchy to score each of the alternatives, allowing us to compare them on a common scale. With the results of the comparison, a thorough sensitivity analysis, and a cost-benefit analysis, we are then able to recommend a simulation alternative to the client.

The final phase, pending acceptance of the recommendation, is Implementation (Phase IV of the SEMP). Implementation consists of three steps – Planning for Action, Execution, and Assessment and Control. Any proposed implementation plan will include, at a minimum, 1) a phased timeline that identifies intermediate objectives, essential tasks, and the critical path, 2) an estimation of the required implementation and life-cycle costs associated with the solution, and 3) other assessment and control mechanisms to help manage the plan.

The framework of this report follows the structure of the SEMP.

Chapter 2: Problem Definition.

2.1 Needs Analysis.

2.1.1. Project Impetus.

In a meeting with LTC Michael Kwinn on 01 October 2003, BG James Moran, PEO Soldier, stated that he needed a simulation for decision support in choosing between alternative systems or components for the Infantry soldier, for expressing quantitatively the differences between candidate systems, and for justifying resource allocation. BG Moran commissioned the Operations Research Center of Excellence (ORCEN) at USMA to conduct a study to develop a roadmap for the use, modification, or development of a simulation, or family of simulations, that will support PEO Soldier decision making.

2.1.2. Initial Problem Statement.

Based upon discussions with our primary stakeholder during our initial project meeting with the Deputy PEO Soldier, Mr. Charles Rash, on 14 November 2003, we obtained the following initial problem statement:

> PEO Soldier needs a simulation that allows the evaluation of platoon effectiveness based upon changes in Soldier tactical mission system (STMS) characteristics.

An STMS is any system, or system of systems, worn or carried by the Infantry soldier on the battlefield and includes such equipment as weapons, load-bearing equipment, communications devices, GPS devices, sensors, tools, etc.

2.1.3. System Decomposition.

We began by looking at a simulation system in general and decomposing it into its primary functions, components, and structural hierarchy. This initial look at the system allowed us to consider its key aspects and served as a starting point for the remainder of our analysis.

The primary functions of a simulation in this case are to support decision-making and to simulate. The primary subfunctions of the simulation system itself are interfacing with the user,

processing inputs, controlling processes, transforming inputs to outputs, processing outputs, and maintaining, self-testing, and managing redundancy. A more in-depth look at functions will be discussed in the functional and requirements analyses sections.

Components are divided by type into structural, operating, and flow. Structural components are static and do not change during the transformation process. For a simulation system, the primary examples are computer hardware (CPU, monitor, IO devices) and the facility itself. Operating components transform inputs into outputs and are dynamic. Primary examples for simulation are the software, architecture, computer code, and algorithms that drive the interactions. Additionally, users, analysts, programmers, maintainers, and subject matter experts (SMEs) provide expertise and controls that affect the transformation. Flow components are those inputs that are transformed into outputs. Examples in this case include actual simulation inputs entered by the user or internal to the software – STMS characteristics, scenarios, entities, units, equipment, etc. Outputs include data that may be converted into measures of effectiveness (MoEs) or measures of merit (MoMs), and visual outputs, such as 2D and 3D playback of the scenario. Other things that flow through the system that may be of particular interest to PEO Soldier are time and money.

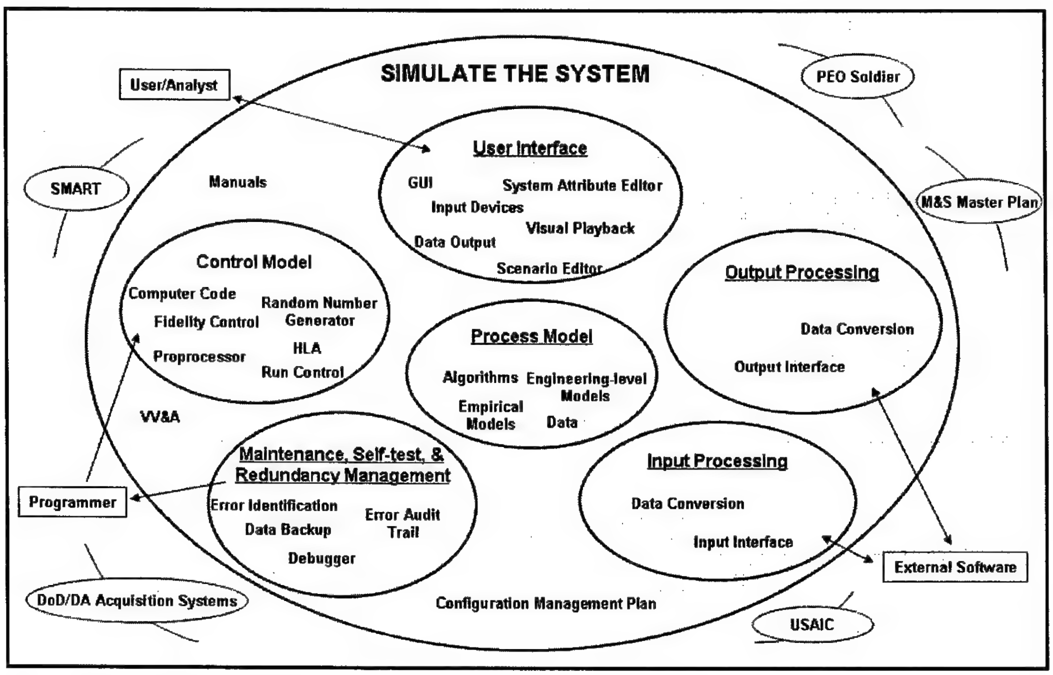

Figure 4. Systems context diagram.

The structural hierarchy within which a simulation falls includes it super-systems (those systems of which the simulation is a part), lateral systems (others systems that are similar in objectives, goals, or structure to the simulation), and its sub-systems. A simulation that meets PEO Soldier's needs is primarily part of the following super-systems: the Department of the Army's (DA's) SMART program, DoD/DA acquisition systems, DA's Modeling and Simulation (M&S) Master Plan, PEO Soldier, US Army Infantry Center (USAIC), simulation federations such as MATREX (Modeling Architecture for Technology, Research and Experimentation), and computer networks. Lateral systems include live and virtual simulations, other analytical methods, prototypes, computer-aided design (CAD) software, training systems, data analysis software, and STMS. Critical subsystems include data, empirical/engineering-level simulations, input systems, output systems, control systems, transformation systems, user interfaces, and maintenance systems. Figure 4, on the previous page, shows a systems context diagram that captures the hierarchical structure and components of the system.

By conducting the above analysis, we identified key aspects of the system under study that must be considered throughout the process. Additionally, by putting the entire system in context, we were able to identify other systems and factors in the environment that directly affect any proposed simulation solution.

2.1.4. Review of Literature and Related Research.

Upon project initiation, our team began to conduct an extensive search of literature. A comprehensive list of references can be found at the end of this report in the Bibliography section. Those references are grouped by the topic areas that we are using to organize the following discussion.

2.1.4.1 Modeling and Simulation Policies and Guidelines.

We started by familiarizing ourselves with the relevant Army and DoD policies, regulations, and guidelines governing modeling and simulation. Some of the most helpful were the documents related to the Army's SMART program. These provided the critical tie-in between policy and best-practices and between acquisition and M&S. The *SMART Reference Guide* briefly describes many of the various simulations being used today (AMSO, 2001). The *Planning Guide* directly applies M&S to system development and describes its intended use in

the acquisition community (AMSO, 2002b). Thus, the SMART documents served as a good starting point for the simulations we would consider and the ideal application of those tools in the acquisition process.

Also useful in the same respect as the SMART documents were the *Army Modeling and Simulation Master Plan* (1997) and the *Army Modeling and Simulation Roadmap* (2003). Key information we found in the *Master Plan* included the Army M&S vision and strategic guidance, M&S management, the components of the M&S lifecycle, and Army-level M&S requirements with their objectives and measures of performance. With the *Master Plan* currently under revision, we referred to the *Roadmap* for updated guidance. That document, still in draft form, updated the Army's purpose, vision and mission for M&S, its goals and objectives, and the organizational structure for M&S management. Recently, a draft version of the new master plan was published, now called *United States Army Modeling and Simulation (M&S) Processes and Procedures* (2004); however, due to the timing of its release, the content of that document was not a factor in our initial results.

Also critical to our understanding of the systems within which we were working were DA regulations, pamphlets, and memoranda. The primary of these is AR 5-11, *Management of Army Models and Simulations* (1997). That document lays out Army policy on M&S management, and guidance on verification, validation, and accreditation (VV&A), configuration management (CM), and data management. DoDI 5000.61, *DoD Modeling and Simulation Verification, Validation, and Accreditation (VV&A)* (2003), and DA Pam 5-11, *Verification, Validation, and Accreditation of Army Models and Simulations* (1999), discuss VV&A requirements in more detail and provided key information that would be crucial to any implementation we recommended. DA Memo 5-15 (2002), concerning high level architecture (HLA) compliance, delineates the requirement that all simulations be HLA-compliant, which later became one of our key constraints. DA Pam 5-XX, *Simulation Support Planning and Plans* (2003), in draft form, describes the requirement for major acquisition programs to have simulation support plans (SSPs) and details the required information for SSPs. The details in this document are very similar to that in Appendix C of the *SMART Planning Guide*. From both, we learned a great deal about the recommended integration of M&S, specifically simulation, into the acquisition lifecycle of major products. AR 5-5, *Army Studies and Analyses* (1996), and its corollary pamphlet, DA Pam 5-5 (1996), describe the general analyses and studies requirements and

include study source information and study report formats. Additionally, they provide detail about study advisory groups (SAGs). Since our recommended solution would be used as part of studies and analyses, those documents helped us understand how the simulation capability would fit into the larger picture.

The final type of regulations we reviewed in this group were those published by the US Army Training and Doctrine Command (TRADOC). Most of these documents serve as clarifications of DA publications with specific application to TRADOC. Therefore, we will only discuss one of those publications here – TRADOC Regulation 71-4, *TRADOC Scenarios for Combat Development* (2001). This document describes the use, development, and approval of scenarios to be used in TRADOC studies and analyses, and, thus, would directly impact any simulation capability we might recommend.

2.1.4.2 Acquisition Policies and Guidelines.

We quickly realized that in order to understand the context of the required simulation capability, we had to gain a sufficient understanding of the DoD and Army acquisition processes. We relied on two different types of documents to do this. The first type directly addresses the acquisition system. At the DoD level, they include Department of Defense Directives (DoDDs), Instructions (DoDIs), and Guidebooks. DoDI 5000.2, *Operation of the Defense Acquisition System* (2003), and the *Interim Defense Acquisition Guidebook* (2002), provide detailed information about the DoD acquisition process including procedures, regulatory information, information technology (IT) considerations, test and evaluation (T&E), resource estimation, human systems integration, acquisition of services, and program management. For the most part, we used these documents to answer specific questions instead of reading the entire publication. At the Army level, the key acquisition system document that we reviewed was AR 70-1, *Army Acquisition Policy*, which generally covers the same topic areas as the DoD *Guidebook*, but with the addition of Army-specific policies. We also reviewed TRADOC Regulation 71-12, *TRADOC System Management*, which discusses management of high-priority materiel systems, to include the establishment of TRADOC Systems Managers (TSMs), TRADOC Program Integration Offices (TPIOs), and TRADOC Project Offices (TPOs).

The other type of publications that we reviewed to increase our understanding of the acquisition system governs capabilities and requirements development. At the DoD level, these

include the Chairman of the Joint Chiefs of Staff Manuals (CJCSM) and Instructions (CJCSI) and DoD architecture documents. CJCSI 3170.01C, *Joint Capabilities Integration and Development System* (2003), provided us a detailed explanation of the process of integrating and developing capabilities and of the required products throughout the materiel lifecycle. The *DoD Architecture Framework, Version 1.0, Volumes I & II* (2003), describe, in detail, how to define the architecture of warfighting operations and business operations within the overall DoD framework. Thus, our simulation solution may, in time, become part of another system's architecture and be used to tie into the overall framework.

At the Army level, we used TRADOC guides to get further detail, specific to the Army, on the development of Initial Capabilities Documents (ICDs) and Capability Development Documents (CDDs). Additionally, we used an AMSO slide to clarify the specific M&S review criteria for those documents. TRADOC Pamphlet 71-9, *Requirements Determination* (1999), describes the requirements determination process, organizational rules, integrated concept teams (ICTs), capstones, future operational capabilities (FOC), science and technology programs (S&T), Advanced Warfighting Experiments (AWE), Advanced Technology Demonstrations (ATDs), and Advanced Concept Technology Demonstrations (ACTDs), studies and analyses, warfighting materiel requirements, and, most importantly for us, M&S requirements integration and approval. All of the above publications showed us not only how our simulation fit in the capabilities development process, but also pointed us to the types of questions that our solution may have to answer for the systems it will support.

2.1.4.3 PEO Soldier Related Documents.

With a basic understanding of the acquisition process and M&S policies, we needed to develop a greater understanding of PEO Soldier – its organization and products. We obtained much of this information through interviews; however, we did rely on some documents for specific information. The *PEO Soldier Portfolio 2003: America's Most Deployed Combat System* provided a general overview of the organization and descriptions of the materiel currently being developed. This was a tremendous resource for developing simulation requirements since it describes the capabilities of the various systems that would need to be modeled. The other documents that we reviewed were all related to the Land Warrior (LW) program. Since Land Warrior is an integrated system of systems, it is an ideal example of what must be modeled in

simulation. Also, since an analysis of alternatives (AoA) is currently being conducted by TRAC-WSMR for the Land Warrior Milestone (MS) C decision, that program drove, in part, our initial implementation timeline. The LW documents consisted of previous studies conducted by AMSAA and other organizations, and taskers for the AoA. Additionally, we used the slides created by TRAC-WSMR for their AoA briefing (Larimer, 2004) to the study advisory group (SAG), which delineated the questions to be answered and their plan for the conduct of the AoA. This presentation proved to be a very valuable source of information. Finally, we referred to a draft SSP, written by Booz-Allen & Hamilton (2000), that attempts to address the integration of simulation into the Land Warrior program; however, that draft was never approved.

2.1.4.4 Methodology Documents.

Much of the systems engineering methodology expertise resided with the members of our study team. However, we used Hatley and Pirbhai's book (1988) to facilitate our functional decomposition and the Department of Commerce's IDEF standards (1993) to compare our methodology with a similar process. Finally, we used *Logical Decision for Windows, Version 5.125* (2003) for the decision analysis portion of our methodology.

2.1.4.5 Doctrine.

We referred to doctrinal manuals when trying to define the simulation modeling requirements, specifically in terms of scenarios, combined arms representation, and the modeling of the functions of the individual soldier. For scenarios, we looked at potential Joint operations using CJCSM 3170.01, *Universal Joint Task List (UJTL)* (2002), and Army operations using FM 7-15, *The Army Universal Task List* (2003). For the operational capabilities that fulfilled the Objective Force vision, we referred to TRADOC Pamphlet 525-66, *Force Operating Capabilities* (2003). For individual soldier tasks and functions we looked at FM 7-8, *Infantry Rifle Platoon and Squad* (2001), and ARTEP 7-5-MTP, *Mission Training Plan for the Stryker Brigade Combat Team Infantry Rifle Platoon and Squad* (2003). We looked at the latter because the current version of Land Warrior is to be Stryker-interoperable.

2.1.4.6 General Documents.

In this category of documents, we were seeking any other work relating to our study. We discovered quickly that others have been researching various aspects of individual soldier modeling in simulation. In fact, we found four studies that directly addressed aspects of our study. The first was a study that served as one of the drivers for our own. That study, titled *Finding a Simulation that Models Both Present and Future Individual Soldier Systems* (Aviles, et al., 2000), conducted at the USMA, sought to identify the best simulation to evaluate capabilities of individual soldier systems. They concluded that no simulation met all the requirements. That study was done on behalf of PM Soldier (PEO Soldier's predecessor organization). However, the information contained therein needed to be updated and their requirements broken down in greater detail.

The second study was conducted by the Soldier Modeling and Analysis Working Group (MAWG) chaired at TRAC-WSMR. That group, consisting of members of numerous Army agencies, identified key soldier modeling requirements and evaluated existing simulations against those requirements. Their report, *Soldier Modeling and Analysis Working Group (MAWG) Evaluation Report* (Larimer, et al., 2004), provides a roll-up of current simulation capabilities by requirement. Because of the shortened nature of our timeline, we relied heavily upon the simulation proponents' responses to the Soldier MAWG surveys (copies furnished to us by TRAC-WSMR), in order to evaluate current simulations. See Appendix E for a list of the questions contained in the surveys.

The third study was conducted by a NATO working group. The report is titled *Model(s) for the Assessment of the Effectiveness of Dismounted Soldier System* [sic] (2001). In this study, the NATO working group evaluated key simulations from numerous member countries against required characteristics. As with the first study we discussed, the NATO results are somewhat dated, and their requirements were not in the detail we desired. However, they served as another base upon which we could conduct our study.

The fourth study was conducted in the Department of Systems Engineering at the USMA in 2002. In it, Dr. Paul West attempted to recreate in simulation the first major battle of the Vietnam War, the battle in the Ia Drang Valley in 1965. The purpose of his study was to "explore the feasibility of replicating a Vietnam-era battle in simulation, using 1960s and Land Warrior technologies," and given that, to "recreate a Vietnam-era infantry battle to provide

vignettes for comparing Land Warrior and non-Land Warrior equipped forces (West, 2002)." Dr. West used the Joint Conflict and Tactical Simulation (JCATS). Their conclusions were that the lack of situational awareness and semi-autonomous behaviors in JCATS required interactor support; therefore, simulating a Vietnam-era battle in a closed-loop simulation was not possible at that time. His conclusions directly reflect the crux of PEO Soldier's problem.

In addition to the above studies, we found some other key documents relating to our research. One of these was *NATO Soldier Modernisation* [sic]: *Measurements for Analysis – a Framework for Modelling* [sic] *and Trials* (1999). The objective of this NATO report was to quantify the achievement goals of individual soldiers and groups of soldiers. The document set measurement levels, described ideal missions and vignettes, discussed key command and control (C2) areas, and listed special operations-other-than-war (OOTW) considerations. The paper by Cosby and Severinghaus (2003) identifies shortcomings in individual and small group soldier modeling due to the changing nature of modern warfare. The paper by Rodriguez (2003) identifies current individual and small team simulation efforts in the virtual training domain. The paper by Cioppa, et al. (2003), describes the current efforts of the Military Operations in Urban Terrain (MOUT) Focus Area Collaborative Team (FACT), or the Urban Operations (UO) FACT as it is now called, to address current gaps in the modeling of urban terrain.

Other references we used included a paper covering analyses of alternatives written by the Army Logistics Management College (ALMC, 2003), that gave a good overview of the conduct of an AoA. We also looked at a paper by the National Security Directorate (2001) that looks at the future requirements of Objective Force Warrior (OFW), now Future Force Warrior (FFW). The technical report by Kwinn and Smith (2001) provided a framework to view the soldier's potential role in network-centric warfare. Finally, the NATO presentation by Jacobs and Brooks gave us a synopsis of human behavior representations (HBR).

2.1.4.7 Conferences.

In addition to reviewing literature and documents, we attended related conferences to gain an understanding of the current state of research. We will discuss three of those conferences here.

We attended the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) held in Orlando in December 2003. I/ITSEC was a very large conference bringing

together the latest in technology and techniques from all of the Armed Services and from industry. The focus of the conference was on simulation for training and education purposes, although analysis was also covered. We spent a tremendous amount of time viewing technology through government and industry exhibits and learning about current research in tutorials and paper presentations. The primary topics that we focused on during our attendance were simulation interoperability, HBR, simulation requirements definition, environmental representation requirements, and communications network modeling. The information we took from I/ITSEC was very valuable to our study.

The second conference that we attended, also in December 2003, was the Winter Simulation Conference (WSC) in New Orleans. WSC was an academic and industry conference covering a wide variety of simulation topics, most of them non military-related. Although there were exhibits here as well, the tutorials and paper presentations were the most valuable source of information. The topics that we focused on here were simulation interoperability, HBR, requirements definition, distributed computing, verification, validation and accreditation (VV&A), and urban operations M&S research.

The third and last conference that we attended was the US – German High Resolution Infantry Workshop held in Monterey, CA, in March 2004. The purpose of this conference was to discuss Infantry soldier modeling issues being faced in common by US and German modelers. During the first portion of the workshop, representatives from both countries presented current research and progress on a variety of related topics. During the second portion of the workshop, participants worked in small groups on the following focus areas: weapons effects and target engagement, human-centric modeling, and urban terrain and environment. Although the workshop was relatively late in the progress of our study, we learned a great deal and were able to refine some of our products as a result.

Our review of literature and related research was a continuous process, and a critical foundation to our study.

2.1.5. Stakeholder Analysis.

In conjunction with our search of pertinent literature and research relating to our project, we were also attempting to capture the needs and opinions of all critical stakeholders. A stakeholder, for our purposes, was anyone who had a vested interest in our problem. To identify

stakeholders, we did so by category: simulation users, simulation developers and maintainers, analysts, SMEs, acquisition organizations, and others. While we attempted to interview a broad range of stakeholders, the compressed nature of our timeline prevented us from interviewing everyone we would have liked and caused us to rely on research and information developed by others.

Our interviews encompassed personnel from the following organizations: TRAC-WSMR's Land Warrior AoA team, TSM-Soldier at Fort Benning, the Modeling and Analysis Team at the Natick Soldier Center (NSC), the Infantry Warrior Team at the Army Materiel Systems Analysis Activity (AMSAA), PEO Soldier and its subordinate project and product managers (specifically members of PM-Soldier Warrior (PM-SWAR), PM-Clothing and Individual Equipment (PM-CIE), PM-Soldier Weapons (PM-SW), and PM-Land Warrior (PM-LW)), Combat^{XXI} developers at TRAC-WSMR, Objective OneSAF (OOS) developers, TRAC-MTRY, and SMEs internal to our organization.

We obtained a tremendous amount of input from our interviews and discussions and we integrated much of what we learned into our products. However, we will discuss further information we received from two particular groups.

2.1.5.1 PEO Soldier and Subordination Organizations.

We held our initial project meeting on 14 November 2003 at USMA. At that meeting, we briefed Mr. Charles Rash, Deputy, PEO Soldier, on our project plan. As a result, we received additional guidance and clarification. We will only discuss the most pertinent of that information here. Mr. Rash indicated that he believed that the solution to their problem would be a suite of simulations, and that a single simulation that could meet all of their needs will not be possible for a long time. He stated that he understood that M&S has limitations and that no M&S will do everything; therefore, he wanted to know what is achievable as input to making informed decisions. He asked us to look at the technologies of other services, but not simulations from other countries. Finally, he asked us to have a recommendation by 31 March 2004 (in 4.5 months).

We presented our first Interim Progress Report (IPR) to Mr. Charles Rash, at PEO Soldier in Fort Belvoir, VA, on 19 December 2003. There, we reported the results of our review of literature and stakeholder analysis to that point, and we received additional clarification.

When asked about what specific types of questions they needed answering, Mr. Rash cited comparative studies between new, proposed systems and current systems. He needed a simulation capability for value-added analysis of new equipment. He wanted to be able to get collective (platoon-level), aggregate measures of effectiveness, but with individual soldier fidelity. He pointed out the fact that often an engineering-level model will show great benefit at the individual system level, but when aggregated into larger, force-on-force models the overall benefit is smaller or even larger. He wanted to be able to quantify that benefit, especially the quantification of the value of situational awareness (SA) / situational understanding (SU). He was looking for a model that would produce results acceptable to the Operations Research / Systems Analysis (ORSA) community. Some of the specific capabilities he brought up were:

- the ability to switch out soldier systems in the simulation;
- the ability to change the equipment mix;
- the representation of platoons, squads, and individuals using tactics, techniques, and procedures (TTPs);
- a human behavior representation that reflects interaction;
- a representation of the handling of casualties;
- a representation of what happens to soldier performance if a system fails; and,
- the ability to replicate unmanned systems.

We conducted a second IPR on 22 March 2004 to Mr. Ross Guckert, Director of Systems Integration, PEO Soldier. However, because of the timing of the IPR, we did not obtain new information that impacted our study.

In addition to meetings with our primary client, we also spoke with M&S representatives at the Project and Product Manager levels. From them, we learned that the PMs are frequently asked to conduct short-suspense "what-ifs," but do not really have the simulation capability to answer those sufficiently. They need simulations for conducting engineering trade-off analyses as well. They also felt that PEO Soldier needed to have greater influence in model development and use.

2.1.5.2 Other Army Agencies.

The primary comment from stakeholders in other M&S agencies was that the data did not exist to populate simulation databases properly. Most recognized the shortcomings of current

simulation technology to meet fully the needs of the Infantry acquisition community. They also pointed us in the direction of related research and projects, many of which were referenced earlier in this report.

2.1.6. Functional Analysis.

We will discuss our functional analysis for this study in two parts. The first part, discussed in this section, covers the general functions of a simulation capability; the second part, in the next section, includes a more-detailed analysis of soldier functions in order to define requirements.

We identified that, at the highest level, this simulation capability must support PEO Soldier decision-making, as well as simulate or represent the soldier in his battlefield environment. While these seem obvious, our original inclination had been to focus on the simulation piece at the expense of decision support. By doing so, we had no way to account for risk or time-related issues. Our resulting functional hierarchy is shown graphically in Figure 5.

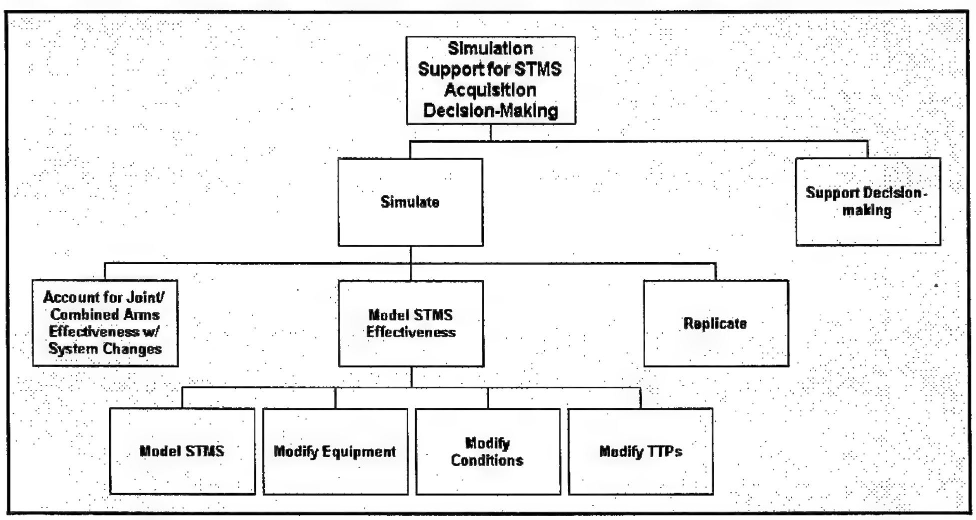

Figure 5. Simulation capability functional hierarchy.

2.1.7. Requirements Analysis.

2.1.7.1 Methodology.

We uniquely applied a common methodology to define our requirements. The first step was conducting a decomposition of the required simulation software functions and arranging them into a functional hierarchy. At the highest level we used Hatley and Pirbhai's generic

template for representing a system's physical architecture, decomposing each function into six subfunctions (Figure 6): 1) provide user interface, 2) format inputs, 3) transform inputs to outputs, 4) control processing, 5) format outputs, and 6) enable maintenance, conduct self-test, and manage redundancy processing (Hatley and Pirbhai, 1998).

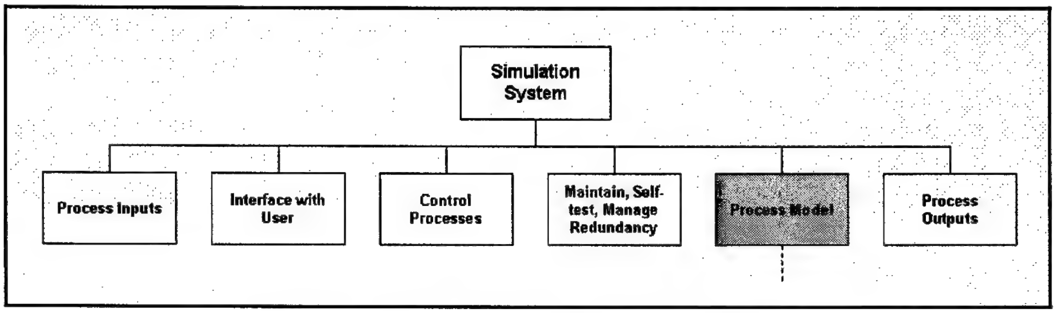

Figure 6. Primary simulation software functions.

Each of these six subfunctions can then be broken down further, as necessary. Five of the six subfunctions above capture the architecture and desired characteristics of the simulation itself. One sub-function – transforming inputs to outputs (the process model) – addresses the modeling aspects of the simulation. We decomposed this function as shown in Figure 7 below.

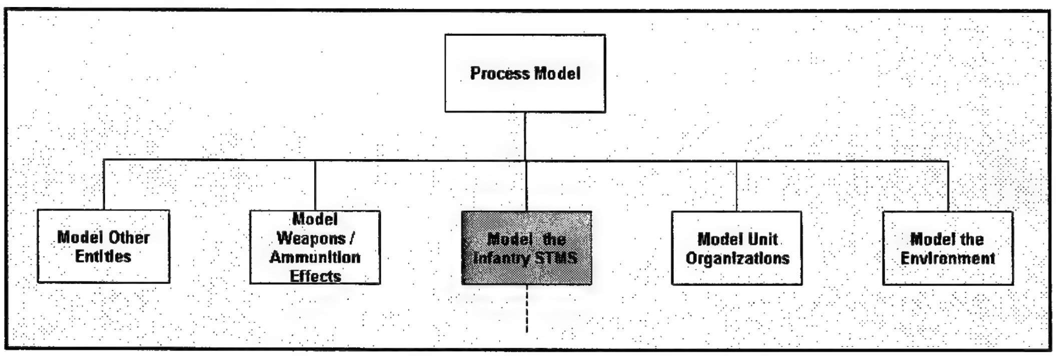

Figure 7. Primary simulation modeling functions.

From here, we focused on modeling the represented entity, and conducting a functional decomposition on it. Since we wanted to have resolution down to the individual Infantryman, the next step consisted of decomposing all of the functions that the soldier executes in the performance of his mission. Because we focused on soldier functions, information was easily obtained from subject matter experts (SMEs), i.e. soldiers. The challenge, then, was organizing the functions into a hierarchy. We worked from both top-down and bottom-up to ensure completeness. Figure 8 shows the highest level of our soldier decomposition. Each of those sub-functions were further broken down. See Appendix B for the entire soldier functional hierarchy.

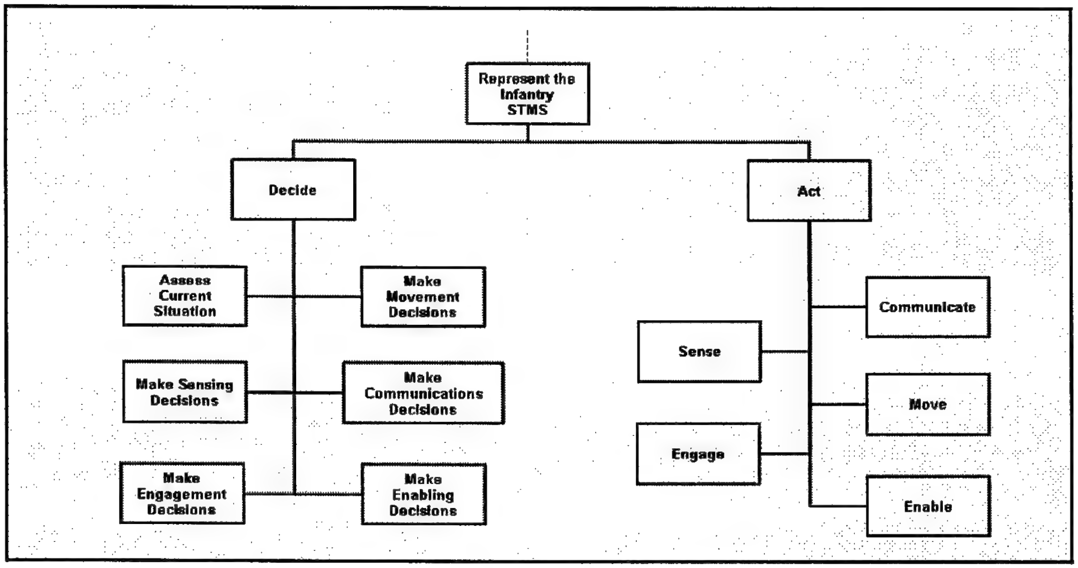

Figure 8. Functional decomposition of primary STMS functions.

The intent of the final set of requirements was to provide a simulation capable of comparing alternate materiel solutions. For that reason, we needed only decompose down to subfunctions that either affect the performance of the soldier system or component, or allow for differentiation between alternative systems. However, in order to have a hierarchy robust enough to consider future systems, we decomposed to the lowest sub-function by which the modeler can reasonably expect a future system to be affected or differentiated. We will address this further in a moment.

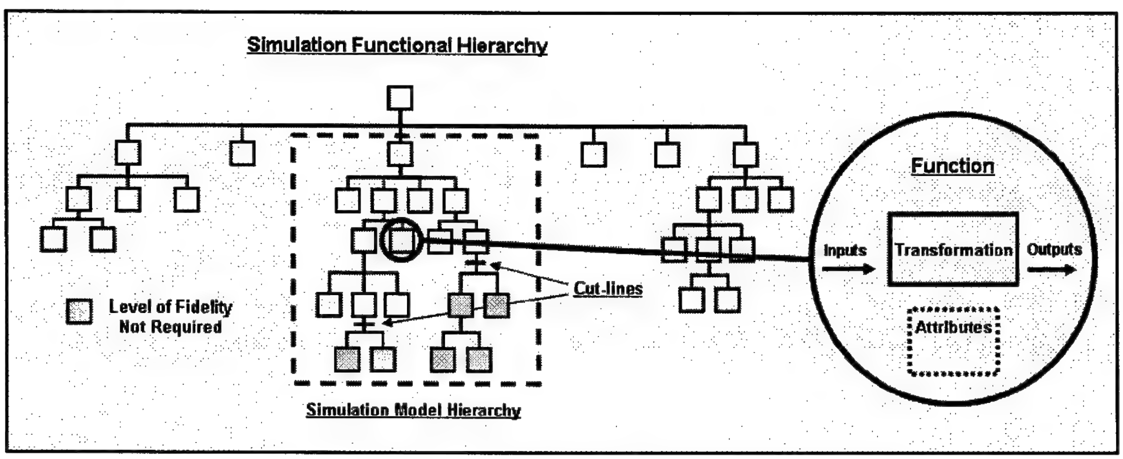

Figure 9. Functional decomposition for requirements analysis.

Once we decomposed the soldier entity's functions and arranged them into a hierarchy, we then conducted input-output analyses. For each function, we identified all of the inputs transformed by the function and the outputs produced. During this process, we also captured the

attributes that affect the transformation, as shown in Figure 9. While this is seemingly simple in theory, it was quite involved in practice.

As an example, we will consider the soldier function of choosing a target to engage. Inputs into this decision include the soldier's own location, the target location, the threat presented by the target, the soldier's perceived probability of hitting the target, other targets, the terrain, the weather, his sector of responsibility, his location in the formation, etc. The primary output is a target choice, which may be an input to the actual engagement function. Attributes of the soldier would include his training level, experience, doctrine, rules of engagement (ROE), role in the unit, etc. All of these attributes affect how the soldier transforms his inputs to an output and may be unique to that soldier. We considered these part of the processing instructions that control the transformation.

The methodology we used had checks to ensure completeness and prevent unintentional redundancy. First, the inputs of a parent node should include all, and omit none, of the inputs of its children nodes. The same is true of the outputs. Failure to meet the above conditions could indicate missing subfunctions, or an incomplete identification of inputs or outputs. Another check was to ensure that any input was either an output of another function or an input into the system itself from the environment. Such analysis assisted us in identifying other combat systems, or entities, on the battlefield that must be represented and would require similar functional decompositions as well.

Upon completion of the overall hierarchy, we then converted the functional hierarchy into simulation requirements. The first step would have been determining the fidelity required of the simulation model, based on the soldier system being evaluated. Ideally, we would determine, for each branch in the model hierarchy, how far down was necessary for system evaluation. We would draw "cuts" in the hierarchy, below which are subfunctions that do not require explicit representation in the current study. From there, we would determine objectives for each lowest-level sub-function (above the cut-line in the model hierarchy) based on the primary stakeholders' input. We would then choose evaluation measures for each of the objectives. For simulation modeling requirements, these measures will likely be binary – whether or not the simulation has that modeling capability – or a constructed scale that is incremented by the model's ability to achieve the objective. However, because we were developing requirements for all potential PEO Soldier systems, not just one under study, we did not draw cut lines, but considered all functions.

We should note that our approach is similar to the Integration Method for Function Modeling (IDEF0), developed by the Air Force in the 1970s and released by the National Institute of Standards and Technology (NIST) as a standard for function modeling in 1993. IDEF0 is a formalized modeling language, with rules and techniques for creating a graphical representation of a system (Department of Commerce, 1993). IDEF0 and our approach share the same underlying methodology centered on a logical extension of common requirements definition tools – functional decomposition and input-output analysis. However, our approach does not demand the same rigorous application of rules and techniques as IDEF0. The sheer complexity of the soldier system on a fluid battlefield makes IDEF0 impractical for our purposes. Therefore, we stopped short of applying a meticulous rule set, such as IDEF0, to our problem.

2.1.7.2 Methodology Advantages and Challenges.

The primary advantage of our process does not concern its mechanics, but rather the fact that we have a process. While many of the simulations currently in development have operational requirements documents (ORDs) that identify simulation requirements, we have not found a document that describes a methodology for developing them.

Another advantage of our process is its contribution to an understanding of the requirements. The functional hierarchy creates a concise picture of the required functions of a candidate simulation. Such a tool is indispensable for presenting results to a client or a manager, or for quickly conveying needs to potential simulation developers. Moreover, the clarity achieved through well-defined functions makes the subsequent requirements more easily understood by the client, modelers, program managers, software engineers, and the subject matter experts (who will help to validate the model). This invariably reduces the potential for disconnect between the client and the software engineers.

An additional advantage of our methodology is that, by identifying the inputs, we implicitly defined the requirements for the representation of the environment. For instance, if an input for the function of firing the soldier's rifle is the level of ambient light, that characteristic must be represented as part of the environment. Also, identifying inputs and outputs illuminated linkages between functions, and between the system (in this case the soldier) and other systems

on the battlefield (e.g. an enemy soldier). Thus, we could identify other battlefield systems that must be represented, and their required level of fidelity.

The entity functional hierarchy with cut-lines has advantages as well. The extensive decomposition of functions, even though the current study may not require it, allows the hierarchy to be used again for other studies. It should also be robust enough to consider future soldier systems with minor modifications instead of having to start over again. Thus, a properly-constructed hierarchy can expand and contract to meet the needs of study. This prevents unnecessary detail that might slow the simulation or consume excessive memory. Those points at which the hierarchy expands and contracts can also serve as 'hooks' onto which other higher fidelity models can link, if necessary. Therefore, instead of having one large model, one can have a lower-fidelity model that links to high-fidelity, engineering-level simulations when needed.

The methodology results could be useful as well after a simulation, or federation of simulations, is chosen for the study. By comparing the simulation to the value hierarchy, the analyst can quickly determine areas for which "work-arounds" will have to be developed, or assumptions made, to bridge capability gaps. Since the inputs and outputs used by the functions are identified, the modeler can see precisely which missing inputs and outputs will have to be generated by alternative means.

All of the above being said, our methodology is not without its challenges. For one, it requires an in-depth analysis for each study, which alone can be quite time-consuming. Additionally, our process requires that the entity functional analysis be done for any class of entity that could be encountered on the battlefield – a step we have not yet done. The required level of fidelity of the other systems may not necessarily be as high as that of the soldier, but analysis must be done for each entity class to determine that level.

2.1.7.3 Requirements.

Early in our analysis, we discovered that the simulation model requirements flowed from two primary needs: the need for realism and the need for a tool to compare candidate soldier tactical mission systems (STMS). The simulation model has to produce valid outcomes based upon the inputs. This fact is certainly not unique to our study, but is the goal of all combat simulations. But how much realism is required? Resource and technology constraints dictate

that we define an appropriate level of fidelity. The answer to that question depends primarily upon the purpose of the simulation. The purpose of our simulation is to provide a decision aid for comparing STMS configurations and distribution. Therefore, the simulation model must represent those inputs and outputs affecting or affected by the system being considered, while still producing a valid result. Otherwise, unique aspects of the systems being compared will not factor into the simulation output, potentially resulting in an uninformed decision. This is currently the case in existing simulations and the reason PEO Soldier commissioned this study.

Any comparison between systems must consider the system's performance with respect to its desired characteristics. According to an engineering problem statement written by the Department of Systems Engineering (2000) at USMA for PEO Soldier, the main STMS characteristics are mission capability, survivability, and trustworthiness. Mission capability and survivability further consist of lethality, mobility, protection, communications, and situational awareness. Trustworthiness consists of reliability, availability, maintainability, sustainability, and usability. The simulation model, then, must provide measures of the system's performance in terms of those characteristics.

Measures used to evaluate the predicted outcomes for one or more characteristics are called measures of effectiveness (MoEs). For instance, a common MoE used to evaluate lethality is the total number of enemy kills. Thus, a higher total number of enemy kills represents a higher degree of lethality. That MoE may depend upon a large number of measures of performance (MoPs). MoPs are lower-level measures that quantify the performance of a specific piece of equipment or human task. Using the lethality example, the total number of enemy kills may be a function of the following MoPs: weapon rate of fire, accuracy, reliability, human aiming error, target location error, etc. It is quite apparent that weapon reliability, a MoP that directly affects the total enemy kills, also directly affects system trustworthiness. This is an example of the interdependence that led us to decompose by function.

Interestingly, our combination of functional decomposition with input-output analyses actually improved our understanding of the desired performance outputs (or MoEs). By identifying the inputs and outputs of every function, we were also identifying MoPs. Since those MoPs directly affect MoEs, we were able to identify unexpected sources of performance contribution that we would have missed using other methods. Thus, for a comparative analysis, our results give PEO Soldier a clearer picture of how their individual systems contribute to the

effectiveness of the soldier system of systems. The following summarizes our requirements. For the detailed functional requirements document we developed, see Appendix C.

Attributes

As we mentioned in the methodology section, a simulation must represent the soldier entity using a complete set of attributes that affect the entity's performance of a function (or transformation of inputs to outputs). These attributes can act as inputs or controls. For example, attributes acting as controls may be rule sets for making a decision, a general knowledge base drawn upon by cognitive processes, or physical constraints affecting performance. Additionally, these attributes can be affected or changed by the process itself. For instance, movement can reduce the soldier's energy level, operations can increase his experience level, and equipment damage can change its physical and performance characteristics. Attributes can be entered directly or be fed by engineering level simulations.

We group the soldier attributes into three categories – mission, personal, and equipment. Mission attributes reflect the soldier's knowledge about his mission and how he is expected to accomplish that mission. They generally apply to all soldiers in the unit. Personal attributes reflect characteristics of the soldier himself, and may, or may not, vary from soldier to soldier. While the simulation may take such data from engineering level models of human performance, these attributes should still factor into the mission level simulation by affecting soldier performance. Personal attribute subcategories include physical, physiological, psychological, mental, and readiness.

Equipment attributes reflect characteristics of the equipment, weapons, or clothing worn by the soldier. They may differ by soldier, depending on the type of equipment he is carrying, but are normally constant for a particular piece of equipment. The actual attributes greatly depend on the specific type and model of equipment being represented. These include weapons and ammunition, sensors, communications, clothing, and other equipment. It is these attributes that PEO Soldier would be interested in altering to reflect different types of equipment. Therefore, these attributes must be modeled explicitly.

Assess the Situation

This first main function serves as a primary driver for practically all soldier decision-making and actions, and may well be the most difficult to model. Within the context of this paper, the assessment function involves the basic aspects of what the military commonly refers

to as METT-TC analysis. Such an analysis centers on the soldier's assessment of his Mission, Enemy situation, Terrain (referred to as environment in this paper), Troops available (such as friendly situation or knowledge of supporting and adjacent units), Time available, and Civil considerations. For the purposes of brevity, any further use of METT-TC directly refers to the soldier's assessment of the situation.

Wherein PEO Soldier's requirements are concerned, this assess function is critical. Not only does an effective assessment obviously enhance the soldier's situational awareness, it has direct and indirect impacts in other areas, such as lethality and mobility (e.g., soldier assessment of weapons/equipment needed to complete mission). In fact, many of the proposed capability enhancements of PEO Soldier systems aim to provide the soldier with improved means for collecting and analyzing information critical to his situational assessment. Accordingly, any simulation that seeks to offer comparative analysis between PEO Soldier systems must certainly model how those systems enhance or detract from the soldier's ability to assess the situation. It is also important to recognize that the soldier's assessment phase never truly ends. In fact, throughout the duration of a particular mission, the soldier is constantly updating his assessment based on physical observations, encounters, and external data fed to him through various conduits (analog or digital communications, voice/hand signals from a squad-mate, etc.).

Sense and Make Sensing Decisions

On the asymmetric battlefield of today, soldiers at every level make decisions based on a sensing of the battlefield. In fact, much, if not all, of what Infantry soldiers do on the battlefield involves varying degrees of sensing. This includes the specific functions of searching, acquiring and tracking targets. Accordingly, the soldier's sensed perception of the battlefield plays a critical role in his decision processes and resulting actions.

PEO Soldier systems directly address this function by providing sensing capabilities that affect inputs into the decision cycle. For example, PEO Soldier systems, such as thermal weapon sights, night vision devices, GPS systems, and other video systems, enhance the soldier's ability to detect, acquire, identify, and track potential targets. Similarly, such systems enable the soldier to refine his METT-TC assessment more efficiently. Logically, by virtue of the enhanced capabilities they provide, these system components will affect soldier decisions. Therefore, any

potential simulation must model those decisions and how they are affected by sensing equipment.

PEO Soldier products also serve to enhance the soldier's physical ability to observe the battlefield. Most are designed specifically for improving his ability to see throughout the EM spectrum – visual, image intensification, infrared, and thermal; however, improvements to the soldier's ability to use his other senses are probably not far into the future. In that vein, we must consider both the soldier's natural and technologically-enhanced sensing capabilities. Additionally, for the sake of realism, the simulation should model the soldier's ability to detect other cues, e.g. hearing movement or weapon reports, or making observations based on fortuitous glances that may shift his attention.

Ultimately, the simulation should reflect how a particular soldier system affects the soldier's sensing capabilities. For example, a future system may propose a fully en-closed helmet. Does this enhance or detract from natural sensing methods (e.g. does it impede peripheral vision and thereby create a tunnel effect; does it dampen sound to such an extent that soldiers are more susceptible to surprise, etc.)? Soldier systems could be differentiated based on how they overcome such problems and to what extent they enhance natural sensing capabilities.

Engage and Make Engagement Decisions

Any simulation must explicitly model the soldier's ability to engage enemy forces, since it is one of the soldier's primary functions. As with any function, however, the actual act of engaging a target cannot occur without some form of decision process associated with it, no matter how hasty. While the decisions rely heavily upon the weapons and equipment that the soldier is carrying, the unit assets at his disposal, and his means of bringing those assets to bear, they are also impacted by the quality of the soldier's METT-TC assessment and his sensing decisions/actions that led to the target in the first place.

PEO Soldier has made great strides in weapon and sensor enhancements that improve engagement decisions. As addressed under the sense function, enhanced sensory capabilities enable the soldier to acquire, identify, and track targets more efficiently. Advanced communications and digital equipment, coupled with GPS and laser targeting devices, will allow the soldier to call upon networked fires with shorter response times and greater accuracy.

Such capabilities, while affecting the soldier's engagement decisions, will also have the obvious additional impact of affecting the actual act of engagement. Products such as aiming

lights, the Integrated Laser White Light Pointer, Multi-Function Laser System, and the Sniper Night Sight should enable the soldier to engage targets with greater accuracy, thereby influencing such measures as the probability of kill, probability of hit, etc. Accordingly, any simulation seeking a comparative analysis of soldier systems must effectively address both the engagement decision cycle and the resulting engagement process.

Move and Make Movement Decisions

Any soldier system will have some impact on his ability to move, including navigating, changing posture, and changing location through various means of movement. Accordingly, any simulation must address the effects, positive or negative, a system has on these functions. For example, while weapons and sensor enhancements certainly increase a soldier's lethality, all of these additional pieces of equipment must be carried. This may have a counter-balancing effect on lethality in that more weight translates to a more fatigued soldier. Thus, the modeling requirements must capture the impacts of the physical weight and arrangement of the systems on soldier movement, navigational capabilities, and signature (his detectability).

Through many of its products, PEO Soldier seeks capabilities that 1) do not physically impede movement and 2) enhance the soldier's ability to navigate. For example, navigational decisions are aided by GPS equipment, the Helmet Mounted Display (HMD), or the Commander's Digital Assistant (CDA). For comparative analysis, a simulation must represent the benefits of those types of equipment in conjunction with comparative cases (e.g., navigational errors caused by the use of only a map and a compass). On a smaller scale, these decisions encompass soldier movement towards cover and concealment.

As previously discussed, the soldier's continual METT-TC assessment triggers the decide/act cycles associated with these functions. The information shared via the CDA, HMD, and communication equipment can aid the soldier in making movement decisions, thereby necessitating representation. Again, the simulation should model any mistakes made in the absence of these devices, as well as the choice of movement methods to avoid detection (slower, crouched, deliberate, etc.).

The actual physical functions of moving from one location to another are not directly aided by current PEO Soldier programs, with the exception of some climbing aids for urban operations (UO). However, future soldier equipment could feasibly include exoskeletons and other muscular aids that would serve to enhance basic human movements and strength.

Regardless, the weight of the equipment carried and worn by the soldier affects these functions. Consequently, in order to differentiate between soldier tactical mission systems (STMS), the simulation should model the impacts of equipment on soldier movement rates, degrees of motion on his joints, limitations in his fine motor skills, etc.

Lastly, the soldier's selection of a particular posture (standing, kneeling, lying down) has a great impact on the outcome of an engagement, both in terms of the accuracy of the firer and the exposure of the target, as well as the exposure of the firer to returned fires. The obvious impacts of such a choice, coupled with the fact that current PEO systems afford soldiers the ability to fire from a reduced exposure position, require representation in any simulation.

Communicate and Make Communications Decisions

The ability to communicate serves as a vital battlefield multiplier for the soldier since it enhances situational awareness, lethality, and protection. Accordingly, the simulation model must consider communication capabilities above, below, and lateral to the soldier. It must consider issues like integration and interoperability with other battlefield digital systems, both mounted and dismounted. It should model enhancements in range and non line-of-sight (NLOS) capabilities. In the case of Land Warrior, communications include not only radios, but the HMD and CDA.

Communication is critically important to current and future soldier systems. In addition to the ability to transmit voice data, soldiers can transmit digital data as well, allowing for a greater exchange of information. Much of the in-formation sent and received by personnel and devices (e.g., information transmitted via satellite or robot) supports soldier decisions on the battlefield and thereby influences his actions. Therefore, it is important that the simulation capture these decisions and functions in order to represent the soldier accurately.

Transmitting includes all types of communication such as verbal, hand-signaling, writing, typing information into a CDA, etc. While a plethora of communication modes creates redundancy, the devices must compete for band-width. Bandwidth constraints or system overload translate to lost information and degraded situational awareness. The simulation must represent these transmissions and the associated impacts on the soldier. The simulation must also model communication with soldier-controlled systems like unmanned aerial vehicles (UAVs) and robots, as well as the time required to communicate (e.g., time required to type and send a written order or graphics).

As with transmissions, receiving communications from other soldiers or data devices is critical to the success of PEO Soldier-equipped entities. It cannot be assumed that all information available to soldier will be received. Therefore, the distinction between what is received by the soldier and what is not is critical for simulation.

Enable and Make Enabling Decisions

Enabling functions reflect the soldier's ability to operate in his surroundings and perform common tasks critical to survival and the performance of the other four main functions. Thus, these actions enable the soldier to engage, move, communicate, and sense, either directly or indirectly, as well as operate in the basic human sense.

In the course of battlefield operations, the soldier will engage in various decide/act cycles that support one or more other functions. Such cycles include the altering of terrain, load manipulation, and basic human operation. In choosing to alter terrain, the soldier acts either defensively to counter a threat or offensively to gain advantage. These alterations might include digging a fighting position to enhance protection or clearing fields of fire to enhance his ability to engage. If moving, he may decide to breach through or move an obstacle in his path by cutting wire, removing mines, etc. These decisions are especially important in urban operations (UOs), in which soldiers must open doors and windows, move furniture out of their way, etc. Because any STMS might positively or negatively impact this ability, the simulation must model it

Similarly, the soldier will make decisions concerning his load based on mission necessity. For instance, upon making contact, the soldier will probably drop his rucksack until the conclusion of the engagement in order to enhance his agility and mobility (thereby enhancing lethality). Likewise, when a unit moves into a pre-assault position, they may leave their rucksacks and unnecessary equipment behind, under guard, until the mission is complete. Other load manipulations might include choosing to pick up an enemy weapon if ammunition is low, or shifting equipment around to make some available for use (e.g., pulling equipment from the rucksack or putting unnecessary equipment into it). Any system will affect the soldier's ability to perform these necessary functions and will likely come with various configuration options. Therefore, at a minimum, the most basic and common of these decisions should be modeled in a simulation.

Other enabling functions include conducting bodily functions (eating, drinking, and sleeping), performing first aid to self and others, and performing equipment maintenance, resupply, and repair. These functions affect how the soldier and his equipment operate and so require representation, to some degree, in the simulation model.

Requirements for Other-Than-Soldier Representation

The previous section discussed our decomposition of the functions of the Infantry soldier, since that was the focus of our effort. However, our requirements would be incomplete if we did not mention other aspects of the simulation model that must be considered. In some cases, the functional requirements imply a modeling capability that should be expounded upon due to its importance. In other cases, we integrate requirements of numerous functions into a cohesive topic.

Representation of the Environment

Representation of the environment is a tremendously complex issue. Our methodology provides a means to deter-mine environmental requirements by identifying inputs and outputs of each function. If some aspect of the environment is an input into a function, then it should be represented to model that function accurately. Additionally, if an output of a function is an effect on the environment, the simulation should model that as well. The requirements and discussion here only touch upon the more important aspects of this representation as they relate to the requirements of PEO Soldier.

At the highest level, the simulation must be capable of representing any type of environment in which the soldier might operate – urban, desert, jungle, swamp, forest, plains, mountains, arctic, and littoral. Within the environment, the simulation must model various aspects of the terrain. Terrain relief, combined with the weight of the soldier's equipment, will affect his ability to move. Relief also impacts whether a one entity can see and, in the case of direct fire weapons, engage other entities. The model should represent the effects of vegetation on round, fragment, and shrapnel trajectories. Additionally, soldiers seek cover from enemy fire behind trees, and concealment from detection behind various types of vegetation. Therefore, those aspects should be modeled. However, the simulation need not necessarily represent each individual plant explicitly. Instead, a random draw to determine whether the soldier can find such cover or concealment can occur based on the type of environment. This implies that the model does not require 3-D representation.

One of the key aspects of terrain that must be modeled is urban terrain, as statistics point to an increased likelihood of military operations in that type of environment. The accurate modeling of structures is critical for assessing the effectiveness of any system in an urban environment. The structure models should be able to represent interior and exterior characteristics, with multiple rooms, multiple floors, construction material properties, windows, doors, and furniture. It should also have attributes that allow the assessment of weapons effects on the various components of the structure. It should affect the soldier's ability to communicate within and between buildings. Additionally, the simulation must model other urban features: vehicles, infrastructure (electric and phone cables; poles; gas, sewer, and water lines; etc), paved areas, businesses, and general urban layout (roads, alleys, blocks, industrial parks, yards and fences, etc).

Another major aspect of the environment is the climate, which can have a significant impact on soldier and equipment performance. Weather conditions (e.g., temperature, humidity, pressure, wind, and precipitation) affect equipment reliability and performance, as well as the soldier's ability to perform tasks. Light conditions affect his ability to sense surroundings. Man-made conditions, such as battlefield obscurants like smoke and dust, chemical and biological contamination, and illumination devices also have a tremendous impact on the soldier and so require representation.

The simulation environment should be dynamic. This requirement reflects the ability of the simulation to alter the terrain and climate during a single run and would ac-count for the effects of the soldier and his weapons, such as blast craters, damage to structures, fire damage, and changes to vegetation from deliberate soldier action. Dynamic climate allows for changes as the day progresses (e.g., temperature, humidity, and barometric changes) and changes due to the effects of soldier and his weapons.

Representation of Other Entities

We did not go into the same detail for other types of entities as that discussed for the representation of the individual soldier. For the required simulation capability, we are concerned primarily with the representation of the soldier. Therefore, models only need represent other entities to the degree that the soldier will observe or interact with them.

For instance, there may be less need to represent an artillery piece explicitly, only the fires request process, the incoming rounds, and their effects. However, for a tank, the simulation

may have to model its physical and vulnerability characteristics, its capabilities, and a realistic portrayal of its behavior. The same is true of aircraft, personnel carriers, trucks, and other systems the soldier may physically encounter on the battlefield.

The simulation must also represent higher headquarters and lateral units, but only to the degree necessary for communications and directives purposes. For instance, if the platoon leader is attempting to communicate with his company commander on the company net, then the traffic from all company elements on that net should be simulated to ensure a realistic representation of delay. Other representations of higher headquarters might include the ability to attach company mortars or an extra squad, for example.

Representation of Network-Centric Warfare

Network-centric warfare is implied in the discussions of many of the soldier functions; however, we will discuss it here as one integrated topic, focusing on its effects on the target engagement process. Clearly, this characteristic of warfare must be represented in any simulation that might be used to evaluate future soldier systems.

The target engagement process can be broken down into five distinct functions, called battlefield information functions, which are search/detect, identify, track/target, engage, and assess. The responsibility for the performance of these functions is shifting away from the individual soldier to a host of systems distributed throughout the battle-field. Thus, sensors may search/detect, identify, and track/target potential enemy targets, engagement logic may trigger an unmanned weapons platform to engage, and sensors may assess the effects of the engagement (Kwinn, 2001).

The soldier may fill any of the battlefield information function roles as either a sensing or engagement platform; however, he may no longer fill all of the roles. Thus, the discussion of soldier functions does not alone capture the network-centric process. While the soldier's core functions may capture his role in that process, the simulation must account for the digital transfer of information between the soldier and other network platforms and how that information affects the functions of the soldier and those platforms.

Representation of System Reliability and Power Requirements

Technological advances in equipment invariably create in-creased power requirements, integration issues, and special maintenance and repair issues. Hence, it becomes necessary to model equipment reliability and power systems.

The modeling of reliability should account for the failure rates of each of the components and how the various potential component failures would affect the system as a whole. This does not require explicit modeling but perhaps an association with probability functions for potential sys-tem errors and probabilistic estimations of the repair times required for those failures. Likewise, the system failures should affect the soldier's ability to perform certain functions and require the soldier to switch to an alternate method of performing that function, if available.

The simulation should represent power requirements based on the mission, power load, and power source capacity, as well as the ability to resupply. Furthermore, the modeled power requirements coupled with reliability should account for the effects of the environment on system attributes.

Representation of Weapons and Ammunition Effects

While our functional discussion implies this type of representation, it merits special mention. In short, the simulation must represent all types of weapons and ammunition that the soldier may carry or encounter on the battlefield.

For direct fire weapons, the simulation should represent kinetic energy weapons, non-lethal weapons, electro-magnetic energy weapons, and other types of weapons de-livered via soldier, vehicle, or aircraft-mounted platforms. The model should consider area and point firing, as well as the various firing modes (single shot, burst, and fully automatic). Similarly, it must include all types of direct fire ammunition (to include non-lethal types).

Indirect fire weapons necessitate similar representation. The model should represent lethal and non-lethal weapons delivered via soldier, towed, vehicle, or aircraft-mounted platforms and should accurately depict the characteristics of the rounds they fire. These characteristics include the particular type of round (high explosive rounds (air burst, point detonated, and delay), white phosphorous, illumination, smoke, smart munitions, etc.), as well as the time to fire, time of flight, and round adjustment requirements. Likewise, the model should account for chemical and biological weapons, their means of delivery, and their effects on the environment and the soldier.

In conjunction with the actual direct and indirect fire systems, the simulation should also model their key firing characteristics (either explicitly or implicitly). Important direct fire parameters include maximum effective range, rates of fire, bias (variable and fixed), random error, and probabilities of hit, kill, and incapacitation for all possible weapon-munition-target

groupings. These must also ac-count for all weapon-sensor pairings, as they will affect the aforementioned probabilities. Important indirect fire parameters include range, lethal radius, ballistic error, dispersion, aim error, target location error, and probabilities of kill and incapacitation due to fragments and blast effects.

The representation of weapons, ammunition, and ex-plosives must include their effects on targets (humans with various levels/types of protection, structures, vehicles, vegetation, terrain, other objects). Such representation should include effects based on the part of the target struck and the level of protection in that area. Injuries should be affected by treatment, time, and the environment. These effects include not only the effects of hitting the target, but also suppressive effects on personnel nearby (varied suppression duration and level based on the ammunition characteristics, the soldier's protection, and his state of mind).

Again, the latest complete version of our detailed functional requirements document can be found in Appendix C.

2.1.8. Revised Problem Statement.

Based upon our needs analysis, the following is our revised problem statement, or effective need:

> Identify and/or develop tactical combat simulation capability for Light Infantry missions at the level of Platoon and below with resolution down to the individual Soldier. The simulation capability must accept, as input, scenarios and Soldier STMS characteristics. It must model the functions of the Soldier in a tactical environment, and provide, as output, the measures of effectiveness (MOEs) used to evaluate STMS. The simulation(s) will provide the analytical capability to support Program Executive Office (PEO) Soldier decision making.

Appendix D includes our engineering problem statement, which lays out our revised problem statement in more detail.

2.2 Value System Design.

2.2.1. Functions and Objectives.

With our initial Needs Analysis complete, we turned to value-focused thinking to provide a system with which we could evaluate the alternative solutions we would develop later. We started with the functional hierarchy we developed previously (Figure 5), keeping those lowest-

level functions (or sub-functions) that would allow us to differentiate between candidate alternatives. For each of those lowest-level functions we determined objectives (defined for our purposes as the desired direction of attainment of an evaluation consideration) based upon the needs and desires of the stakeholders. In our process, we treat total cost as an independent variable and therefore do not account for it in the value hierarchy. We will look at cost after all alternatives have been scored. The functions and objectives can be seen in the completed value hierarchy shown below in Figure 10.

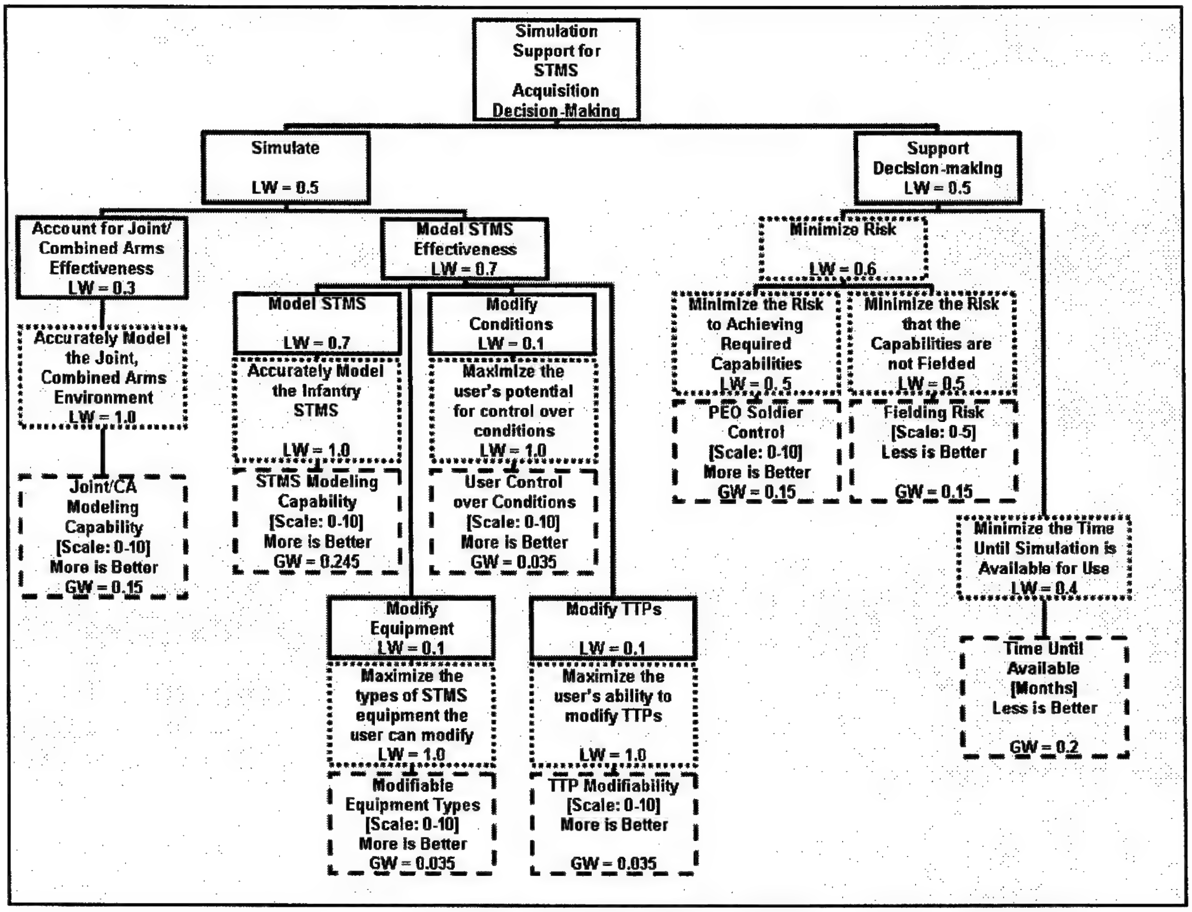

Figure 10. Value hierarchy.

2.2.2. Evaluation Measures.

Below each objective, we selected an evaluation measure that we would use to measure the degree of attainment of that objective. Each evaluation measure consists of a name, a complete description, its units, and whether more or less is better. Because of the subjective nature of our system requirements, most of our evaluation measures were defined in terms of

constructed scales, each level indicating an incremental change in the attainment of that objective. The following sections describe our evaluation measures.

2.2.2.1 Joint/Combined Arms Modeling Capability.

This evaluation measure supports the objective *accurately model the Joint, combined arms environment* under the sub-function *account for Joint / combined arms effectiveness.* It is a constructed scale, with integer values between 0 and 10. We defined it as a measure of the accurate modeling of the relevant combined arms and Joint assets, to the degree required for STMS comparative analysis (e.g., autonomous calls for fire, communications interfaces with naval gunfire (NGF), close air support (CAS), unmanned aerial vehicles (UAVs)). Therefore, a level of 0 corresponds to no relevant Joint or combined arms assets being modeled and a level of 10 corresponds to all relevant Joint and combined arms assets being modeled. For more detail about the scale between the endpoints, see Figure 29 in Appendix F.

2.2.2.2 STMS Modeling Capability.

This evaluation measure supports the objective *accurately model the Infantry STMS* under the sub-function *model STMS.* It is a constructed scale, with integer values between 0 and 10. We defined it as a measure of the accurate modeling of STMS functions, including actions and decisions, required for STMS comparative analysis. See the detailed requirements in Appendix C for more information about the soldier functions (and their inputs and outputs) that should be modeled. Therefore, a level of 0 corresponds to no STMS functions being modeled and a level of 10 corresponds to all STMS functions being modeled. For more detail about the scale between the endpoints, see Figure 31 in Appendix F.

2.2.2.3 Modifiable Equipment Types.

This evaluation measure supports the objective *maximize the types of STMS equipment the user can modify* under the sub-function *modify equipment.* It is a constructed scale, with integer values between 0 and 10. We defined it as a measure of the amount of STMS equipment that can be changed by the user for comparative analyses. Implicit in that definition is the requirement that the STMS equipment be represented in the first place. See the *PEO Soldier Portfolio* (2003) for more detail about the types of equipment that must be modeled and

modified. Therefore, a level of 0 corresponds to no STMS equipment being modifiable and a level of 10 corresponds to all STMS equipment being modifiable. For more detail about the scale between the endpoints, see Figure 33 in Appendix F.

2.2.2.4 User Control over Conditions.

This evaluation measure supports the objective *maximize the user's potential for control over conditions* under the sub-function *modify conditions*. It is a constructed scale, with integer values between 0 and 10. We defined it as a measure of the amount of control the user has over conditions to the degree required for comparative analysis, to include dynamic weather and terrain conditions. Therefore, a level of 0 corresponds to no control over conditions and a level of 10 corresponds to complete control over conditions. For more detail about the scale between the endpoints, see Figure 35 in Appendix F.

2.2.2.5 Modify TTPs.

This evaluation measure supports the objective *maximize the user's ability to control tactics, techniques, and procedures (TTPs)* under the sub-function *modify TTPs*. It is a constructed scale, with integer values between 0 and 3. We defined it as a measure of the user's ability to modify the TTPs within the simulation. Therefore, a level of 0 corresponds to no modification capability and a level of 3 corresponds to direct user modification (e.g., via decision tables or behavior composition GUI). For more detail about the scale between the endpoints, see Figure 37 in Appendix F.

2.2.2.6 PEO Soldier Control.

This evaluation measure supports the objective *minimize the risk to achieving required capabilities* supporting the objective *minimize risk* under the function *support decision making*. It is a constructed scale, with integer values between 0 and 10. We defined it as a measure of the amount of control ("seat at the table") PEO Soldier will have for the given alternative with regards to system development and future modifications. Therefore, a level of 0 corresponds to no control and a level of 10 corresponds to complete control. For more detail about the scale between the endpoints, see Figure 39 in Appendix F.

2.2.2.7 Fielding Risk.

This evaluation measure supports the objective *minimize the risk that the capabilities are not fielded* supporting the objective *minimize risk* under the function *support decision making*. It is a constructed scale, with integer values between 0 and 5. We defined it as a measure of the risk that the simulation development will not be completed (e.g. due to budget cuts, project failure, policy and regulation changes, etc). Therefore, a level of 0 corresponds to no risk and a level of 5 corresponds to very high risk. For more detail about the scale between the endpoints, see Figure 41 in Appendix F.

2.2.2.8 Time until Available.

This evaluation measure supports the objective *minimize the time until the simulation is available for use* supporting the function *support decision making*. It is a natural scale, measured in months. We defined it as the number of months from May, 2004, until a capability usable for AoA purposes (to the degree that it will be developed) is available for use by PEO Soldier or its designated representative. See Figure 43 in Appendix F.

2.2.3. Weighting.

Once the hierarchy was complete, we assigned local weights (LW) to the functions and objectives based upon the needs and desires of our client, collected as part of our stakeholder analysis. For this discussion, it is helpful to refer back to Figure 10, the completed value hierarchy. Local weights indicate the value of that function or objective versus others on the same branch and level in the hierarchy, and must sum to 1.0 (within each branch and level). For example, the highest level functions are *simulate* and *support decision-making*. We assigned them both a value of 0.5, indicating that they are equally important to the client. On the next level, under *simulate*, we assigned *account for Joint / combined arms effectiveness* a value of 0.3 and *model STMS effectiveness* a value of 0.7, indicating the much higher value to the client of modeling the Infantry soldier. See Table 1 for a summary of the local weights assigned to the functions and objectives. It is normally not as accurate to assign weights from top-down. However, due to the simplicity of our hierarchy (few levels and branches), we determined that working top-down would still provide accurate weights. Our resulting global weights confirmed that.

We derived the global weights (GW) for each of the evaluation measures by multiplying the local weight of each objective and function along the branch of the hierarchy from the evaluation measure to the top. Using Table 1 below, the equivalent calculation would be to multiply the local weights from right to left for each row in the table. The resulting value for each row would be the global weight of the evaluation measure supporting the right-most objective. The global weights indicate the relative stakeholder value of each of the evaluation measures with respect to all of the others and sum to 1.0. Table 2 contains a list of the evaluation measures, sorted by global weight. Therefore, the measures are listed by relative importance to the client.

Function	Local Weight	Function/Objective	Local Weight	Function/Objective	Local Weight	Function/Objective	Local Weight
Simulate	0.5	Account for Joint/CA Effectiveness	0.3	Accurately model the Joint/CA Environment	1.0		
		Model STMS Effectiveness	0.7	Model STMS	0.7	Accurately Model the Infantry STMS	1.0
				Modify Equipment	0.1	Maximize the Types of STMS Equipment the User Can Modify	1.0
				Modify Conditions	0.1	Maximize the User's Potential for Control over Conditions	1.0
				Modify TTPs	0.1	Maximize the User's Ability to Modify TTPs	1.0
Support Decision-making	0.5	Minimize Risk	0.6	Minimize the Risk to Achieving Required Capabilities	0.5		
				Minimize the Risk That the Capabilities Are Not Fielded	0.5		
		Minimize the Time until Simulation is Available for Use	0.4				

Table 1. Local weights of functions and objectives.

We can now use the completed value hierarchy, shown in Figure 10, to evaluate alternatives using multiple, and often competing, objectives or attributes. Functions in that figure are identified by a solid line, objectives by a dotted line, and evaluation measures by a dashed line.

Evaluation Measure	Global Weight
STMS Modeling Capability	0.245
Time until Available	0.200
Joint/CA Modeling Capability	0.150
PEO Soldier Control	0.150
Fielding Risk	0.150
Modifiable Equipment Types	0.035
User Control over Conditions	0.035
TTP Modifiability	0.035

Table 2. Evaluation measures sorted by global weight.

Chapter 3: Design and Analysis

3.1 Alternatives Generation.

3.1.1. Generation.

Our next step after initial completion of the Problem Definition phase – the most important and resource-intensive phase – was to look at candidate solutions to the problem. We generated a large number of alternatives from the following categories: 1) using existing simulation capabilities; 2) using simulations under development; 3) modifying simulations under development; 4) using a combination of the previous three categories; and, 5) creating a new simulation capability. For existing simulations and simulations under development, we generally considered the same simulations as those looked at by the Soldier MAWG, with some exceptions. We considered only domestic simulations, since we received direct guidance from our client not to consider models developed by foreign countries. The following are brief descriptions of the alternatives we developed, by group.

3.1.1.1 Existing Simulations.

In this set of alternatives, PEO Soldier would use a currently-existing simulation. They may attempt to influence future developments by presenting their requirements; however, they would not provide any resources to the developers, except as required to obtain, use, and maintain the system. The following are the alternatives we considered in this set.

Agent-based models (ABMs). We considered the following ABMs, all part of the Marine Corps' Project Albert: MANA, Pythagoras, and Socrates. These models are closed-loop, agent-based, time-sequenced, stochastic models. They resolve down to the individual combatant. These models (often called distillations) represent first-order behaviors, but do not use the complex, physics-based algorithms characteristic of other constructive simulations.

Combined Arms and Support Task Force Evaluation Model (CASTFOREM). The proponent for this model is TRAC – White Sands Missile Range (TRAC-WSMR). It is a closed-

loop, event-sequenced, stochastic simulation. It resolves down to the individual combatant, vehicle, or platform.

Janus. The proponent for this simulation model is TRAC-WSMR. It is a primarily HITL (but with closed-loop execution possible), event-sequenced (with some time-sequenced exceptions), stochastic model. It resolves down to the individual combatant, vehicle, or platform.

Joint Conflict and Tactical Simulation (JCATS). The proponents for this simulation are Lawrence Livermore National Laboratories (LLNL) and the Joint Warfighting Center (JWFC). It is a primarily HITL (but with closed-loop execution possible), event-sequenced, stochastic model. It resolves down to the individual combatant, vehicle, or platform.

One Semi-Automated Forces Testbed Baseline (OTB). The proponent for this simulation is PEO Simulation, Training and Instrumentation (PEO-STRI). It is capable of both HITL and closed-loop execution, event-sequenced, and stochastic. It resolves down to the individual combatant, vehicle, or platform.

Squad Synthetic Environment (SSE). This virtual simulation is developed by the Advanced Interactive Systems (AIS) Company and is used extensively at the Soldier Battle Lab at Fort Benning, GA. It is a HITL, virtual simulation. It resolves down to the individual soldier.

Vector in Commander (VIC). The proponent for this model is TRAC – Fort Leavenworth (TRAC-FLVN). VIC is a closed-loop, event-sequenced, deterministic model that resolves down to the battalion level.

3.1.1.2 Simulations under Development.

In this set of alternatives, PEO Soldier would use the end product as it is developed. They may attempt to influence the process along the way by presenting their requirements; however, they would not provide any resources to the developers, except as required to obtain, use, and maintain the system. The following are the alternatives we considered in this set.

Advanced Warfighting Simulation (AWARS). The proponent for this model is TRAC-FLVN. AWARS is a closed-loop, event-sequenced, deterministic model currently being developed to replace VIC. The model will resolve down to the battalion level.

Combined Arms Analysis Tool for the XXIst Century (Combat^{XXI}). The proponent for this model is TRAC-WSMR. Combat^{XXI} is a closed-loop, event-sequenced, stochastic model

currently being developed to replace CASTFOREM. It will resolve down to the individual combatant, vehicle, or platform.

Infantry Warrior Simulation (IWARS). The proponents for IWARS are the Natick Soldier Center and AMSAA. IWARS is a primarily closed-loop (but capable of HITL operation), time-sequenced with event interruptions, stochastic model currently being developed to replace both the Natick Soldier Center's Integrated Unit Simulation System (IUSS) and AMSAA's Infantry MOUT Simulation (AIMS). It will resolve down to the individual soldier.

One Semi-Automated Forces Objective System (OOS). The proponent for this simulation is PEO Simulation, Training and Instrumentation (PEO-STRI). It is capable of both HITL and closed-loop execution, event-sequenced, and stochastic. It resolves down to the individual combatant, vehicle, or platform. It is currently being developed to replace Janus, JCATS MOUT, and OTB.

3.1.1.3 Modifying Simulations under Development.

In this set of alternatives, PEO Soldier would provide resources to a simulation currently under development in order to have their requirements met. The amount of resources depends upon, among other things, the projected capability of the simulation, the architecture of the software, the programming, operating, and maintenance costs of the simulation developer, and the developer's willingness to implement PEO Soldier requirements. For this set, we considered the modification of all four simulations under development already considered: AWARS, Combat^{XXI}, IWARS, and OOS.

3.1.1.4 Combining and/or Modifying Existing and Developing Simulations.

This set of alternatives could encompass any combination of the previous three categories. At this point, we are only considering combinations of the eleven simulations already discussed. We will refine, and further define, this alternative set later.

3.1.1.5 New Simulation.

This is a single alternative in which PEO Soldier would entirely resource a simulation capability that will meet their requirements. They would assume all responsibilities associated with the entire lifecycle of this product.

3.1.2. Feasibility Screening.

3.1.2.1 Constraints.

Not all of the alternatives that we identified above were feasible. Our previous analyses (primarily our stakeholder analysis) revealed constraints that any candidate solution would have to satisfy in order to be considered further. The primary constraints that we considered (with the source of the constraint in parentheses) were:

- the user must be able to alter STMS characteristics within the simulation (client);
- the user must be able to enter and modify a scenario into the simulation (client);
- the simulation must be at the resolution of the individual Infantry soldier (client);
- the simulation software must be high level architecture (HLA) compliant (regulatory requirement); and,
- the simulation must be capable of closed-loop (non-human-in-the-loop) execution (our team).

We determined that the last constraint was appropriate because our solution would be used primarily for analysis. Therefore, in order to reduce the error associated with human learning and experience, as well as the challenges of finding subjects on short notice, we required that the simulation solution be able to run non-HITL. We did, however, leave open the possibility that in some cases, HITL execution may be appropriate.

3.1.2.2 Feasibility Screening Matrix.

After identifying the key constraints, we had to screen out those alternatives that were clearly infeasible. To do that, we constructed a matrix in which we compared each of our original alternatives to each constraint. See Table 3. If an alternative failed to satisfy a constraint, it received an "NG," indicating *no-go*, in the table with the reason why; otherwise, it received a "G," indicating *go*. If an alternative failed to meet even one constraint, it was eliminated from further consideration, indicated by an "NG" in the RECAP column. As a result of this analysis, the following alternatives were eliminated.

3.1.2.3 Eliminated Alternatives.

The elimination of an alternative does not imply that the simulation is bad. It only indicates that, given the constraints discussed above, it cannot be a solution to our problem. In fact, the use of many of the eliminated simulations for Infantry soldier modeling is quite appropriate in many cases. For instance, currently only ABMs have the capability to answer first-order behavior questions that may be critical for certain types of analyses. The SSE is a premier simulator that can answer equipment usability questions that no other simulation can. Therefore, elimination from our consideration here does not imply that it will not factor into the final overall solution indirectly.

	Alter STMS Characteristics? (Yes)	Enter Scenario? (Yes)	HLA Compliant? (Yes)	Soldier Entity Resolution? (Yes)	Aggregate to Platoon? (Yes)	Closed Loop Capable? (Yes)	RECAP
ABMs	NG (No)	G	NG (No)	G	G	G	**NG**
CASTFOREM	G	G	NG (No)	G	G	G	**NG**
Janus	G	G	G	G	G	G	**G**
JCATS	G	G	G	G	G	G	**G**
OTB	G	G	G	G	G	G	**G**
SSE	G	G	G	G	G	NG (No)	**NG**
VIC	G	G	G	NG (No)	G	G	**NG**
AWARS*	G	G	G	NG (No)	G	G	**NG**
Combat^{XXI}*	G	G	G	G	G	G	**G**
IWARS*	G	G	G	G	G	G	**G**
OOS*	G	G	G	G	G	G	**G**
Combination	G	G	G	G	G	G	**G**
New Simulation	G	G	G	G	G	G	**G**
* These simulations, for screening purposes, are considered together whether modified or used as is.							

Table 3. Feasibility screening matrix.

ABMs. These models failed to meet two of the constraints. First, because they are distillations, they are not intended to model the wide array of physics-based effects associated with the combat environment. Therefore, they do not have the level of detail with regard to STMS characteristics to allow the creation of STMS components within the simulation. Secondly, they are not HLA compliant since they are not yet intended to federate directly with existing combat simulations.

CASTFOREM. This model is not HLA-complaint and was eliminated as a result. However, Combat^{XXI}, which is to replace CASTFOREM, was not eliminated and would be the appropriate model to consider anyway.

SSE. The Squad Synthetic Environment is a virtual simulation and was eliminated because it cannot execute without a human-in-the-loop.

VIC. This simulation was eliminated because it does not resolve down to the individual soldier.

AWARS. This simulation was eliminated because it does not resolve down to the individual soldier. Elimination of this alternative also implied the elimination of the modification of this software as an alternative. Since the intent of this simulation is for higher-level analyses, modifying it to meet PEO Soldier's requirements would not fit into the purpose of the model.

3.1.3. Alternative Optimization.

The only alternative (or alternative set) that required further optimization was the combination set. We mentioned previously that this set could include any combination and/or modification to the eleven simulations listed in both the existing and under-development categories. However, we narrowed down that list to one optimized alternative: the modification of and linkage between Combat^{XXI}, IWARS, and OOS. In this alternative, PEO Soldier provides resources to all three feasible simulations currently under development in order to have their requirements met. The amount of resources depends upon, among other things, the parsing of the requirements between the simulations, the projected capabilities of the simulations, the architectures of the software, the programming, operating, and maintenance costs of the simulation developers, and the developers' willingness to implement PEO Soldier requirements.

Our reasoning for considering only this alternative in the set is as follows. Five of the original eleven simulations were eliminated in feasibility screening and were not necessary to consider further. OOS is intended to replace Janus, JCATS MOUT, and OTB. That left three simulations: Combat^{XXI}, IWARS, and OOS. Since each of them have unique characteristics, we saw no need to narrow them down any further. Fortunately, their status as simulations under development gives PEO Soldier a better opportunity to integrate their requirements into the initial development of the product.

3.2 Modeling and Analysis.

With our initial list of alternatives narrowed down to only those which were feasible, we modeled each of the alternatives to determine data for each of the evaluation measures. As mentioned previously, most of the evaluation measures were constructed scales. Therefore, the

process of determining values was subjective. Additionally, all but three of the eleven alternatives were either under development or did not exist at all. As a result, we had to estimate values based upon existing documentation, projected capability, and subject-matter expertise. Because of the subjectivity and incomplete information involved, we often had to assess values for the alternatives by comparing them against each other, instead using the ideal method of assessing each alternative by itself. Therefore, the scores are more accurate when considered relative to each other rather than independently. The following discussion describes our scoring of the alternatives by evaluation measure. Recall the discussions in Section 2.2.2 and the figures in Appendix F defining each of the measures. Table 4 below, the raw data matrix (RDM), summarizes the results of the alternative modeling. Be aware that, when looking at the RDM, a lower value may more desirable than a higher one in some cases.

	Janus	JCATS	OTB	Cbt XXI	IWARS	OOS	Mod Cbt XXI	Mod IWARS	Mod OOS	Combine	New Sim
Joint/CA Modeling Capability	5	6	6	6	4	7	7	5	8	9	10
STMS Modeling Capability	1	3	3	4	7	5	5	8	6	9	10
Modifiable Equipment Types	5	6	6	7	8	7	8	9	8	9	10
User Control Over Conditions	6	6	6	7	7	7	8	8	8	9	10
TTP Modifiability	1	1	2	3	3	3	3	3	3	3	3
PEO Soldier Control	0	0	0	1	2	1	4	6	4	6	10
Fielding Risk	0	0	0	3	3	2	2	2	2	2	4
Time Until Available	0	0	0	12	29	17	12	29	17	29	71

Table 4. Raw data matrix (RDM).

3.2.1.1 Joint/Combined Arms Modeling Capability.

This evaluation measure assesses the alternative's ability to represent the Joint and combined arms battlefield to the degree required for STMS comparative analysis. To model alternatives on this scale, we considered the following capabilities: representing the Joint/combined arms assets themselves in terms of their actions and their behaviors, and representing the soldier's interaction with them (calls for fire, communications, exchange of digital information, etc). Existing simulations (Janus, JCATS, and OTB) as a whole represent Joint and combined arms fairly well; however, they do not represent the interaction with the soldier as well. In fact, those three simulations are primarily designed for human-in-the-loop (HITL) interaction. Therefore, we assigned them all a baseline level of 5. JCATS scored slightly higher (a value of 6) because of its use of limited behaviors for robotics control and its use for special operations training (thereby integrating special operations assets that interact with

the individual special operations soldier). We scored OTB a level of 6 because of its limited behaviors for certain combined arms assets (e.g., standard battle drills).

For Cbt^{XXI}, we assessed a level of 6 because that software will model many of the interactions with Joint and combined arms assets through decision tables; however, its focus is not at the individual soldier level and thus might not capture interactions with the soldier in detail. On the other hand, IWARS is designed to represent the individual soldier with a high level of fidelity, but its requirements for Joint and combined arms asset representation are much less. We scored it at a 4. OOS intends to have a large Joint and combined arms capability and behavior composition tools. We scored it at a 7.

For the modified alternatives, we made the assumption that PEO Soldier infusion of resources into any of the previous three simulations could raise their level by a point, giving Mod Cbt^{XXI} a 7, Mod IWARS a 5, and Mod OOS an 8. We scored the Combine alternative at a 9 because using a combination allows PEO Soldier to capitalize on the combined arms and Joint strengths of Cbt^{XXI} and OOS while representing interactions with the high-fidelity soldiers in IWARS. Therefore, it should at least have the level of Mod OOS (8) and gain another point through linkage. Finally, for the New Sim alternative, we assumed that PEO Soldier could have programmed exactly what it needed into the simulation, giving it a level of 10.

3.2.1.2 STMS Modeling Capability.

This evaluation measure assesses the alternative's ability to represent the functions of the soldier in the detail required for STMS comparative analysis. When first looking at the levels we assigned to the various models, the reader may be surprised to see particularly low values. Keep in mind that we want a model that can represent such items as the Commander's Digital Assistant (CDA) and Helmet-Mounted Display (HMD) and their effects on soldier performance. Our decomposition of the soldier revealed eleven functions of the soldier that require modeling. Six of those fall under the *decide* function. Therefore, any simulation that does not model soldier decisions, or mental processes and their effects on the soldier, started with a level of 4.5 (five elevenths of the total ten points), and that assumes complete representation of soldier action functions. Appendix C (our requirements document) indicates the high level of fidelity we are seeking; therefore, scores start very low. This does not indicate a poor simulation, only that it does not score well against the highly-detailed requirements we developed.

We scored Janus at a 1 because representation of the soldier is only at the most basic level. It does not have behavior models and, at the soldier level, does not represent actions at a very high fidelity. JCATS scored a 3 because of its somewhat more detailed individual soldier representation, especially in terms of the urban operations (UO) environment and special operations forces. We scored OTB a level of 3 because of its limited behaviors (e.g., standard battle drills), its absorption of Infantry soldier modeling originally programmed into DISAF (Dismounted Semi-Automated Forces), and its integration with the Squad Synthetic Environment used for Infantry training and analysis at Fort Benning.

For Cbt^{XXI}, we assessed a score of 4 because, while it can model behaviors through use of decision tables, it does not model high-fidelity soldiers well, especially in a MOUT environment. On the other hand, IWARS is designed to represent the individual soldier with a high level of fidelity and with behaviors, and so we scored it at a 7. OOS will model the Infantry soldier, integrating all of what OTB already has, and adding extensive behaviors. However, its projected soldier entity capability does not appear to be at the fidelity that IWARS will. We gave it a level of 5.

For the modified alternatives, we again made the assumption that PEO Soldier infusion of resources into any of the previous three simulations could raise their level by one, giving Mod Cbt^{XXI} a 5, Mod IWARS an 8, and Mod OOS a 6. We scored the Combine alternative at a 9 because using a combination allows PEO Soldier to leverage the capabilities of the three simulations. Thus, it should at least score the level of Mod IWARS (8) and gain another level through linkage. Finally, for the New Sim alternative, we assumed that PEO Soldier could have programmed exactly what it needed into the simulation, giving it a level of 10.

3.2.1.3 Modifiable Equipment Types.

This measure represents the user's ability to modify the equipment that the individual soldier is carrying (or components of the STMS). The three existing simulations, whether or not they model soldier functions in enough detail, have a fairly extensive capability to alter equipment, giving them at least a level of 5, our baseline. We scored Janus at the baseline level of 5 because its representation of the soldier is only at the most basic level. JCATS and OTB scored slightly better than Janus (level of 6) because of extended capabilities programmed through association with the Soldier Battle Lab (SBL) at Fort Benning.

For Cbt^{XXI}, we assessed a level of 7 because it is a tool being designed for analysis, and therefore, will have a robust capability to alter equipment for analysis purposes. OOS will include an extensive capability to alter equipment as well, and therefore was scored a 7. IWARS, because it is being designed for Infantry STMS analysis, should have an even greater ability to alter equipment, especially STMS equipment, and thus scored an 8.

For the modified alternatives, we again made the assumption that PEO Soldier infusion of resources into any of the previous three simulations could raise their level by one, giving Mod Cbt^{XXI} an 8, Mod IWARS a 9, and Mod OOS an 8. We scored the Combine alternative at a 9 because using a combination should at least score the level of Mod IWARS (9), but would not quite reach the ideal level of 10. Finally, for the New Sim alternative, we again assumed that PEO Soldier could have programmed exactly what it needed into the simulation, giving it a level of 10.

3.2.1.4 User Control over Conditions.

This measure represents the user's ability to modify conditions, to include the scenario and the environment. The three existing simulations allow the user to control the initial conditions by entering the mission/scenario and altering the environmental conditions. However, the detail of the conditions is not at the required resolution for Infantry soldier analysis. For instance, the user cannot control environmental conditions that change rapidly in time and space during a single run of the simulation. Therefore, we scored Janus, JCATS, and OTB at a level of 6. For the simulations under development – Cbt^{XXI}, IWARS, and OOS – we assumed an improvement in the modifiable resolution of the environment, giving them a level of 7. For the modified alternatives, we again made the assumption that PEO Soldier infusion of resources into any of the previous three simulations could raise their score by a point, giving Mod Cbt^{XXI}, Mod IWARS, and Mod OOS a level of 8. We scored the Combine alternative at a 9 and the New Sim alternative a value of 10.

3.2.1.5 Modify TTPs.

For this measure, we used only four levels (0-3) to evaluate the user's ability to model tactics, techniques, and procedures (TTPs). At the lowest level (0), no modification of TTPs is possible. No alternatives fell into this category. The next level (1) allows modification through

scripting only. Simulations in this category have no behavior models. The only way to affect TTPs in these is to script movement and decisions or to use HITL. Janus and JCATS fell into this category. The next level (2) allows modification through changes in the code only. OTB, with its limited behaviors, fell into this capability. The highest level (3) indicates a capability that allows users to modify TTPs through the use of a behavior modification tool and/or decision tables. The remaining simulations will all be in this category.

3.2.1.6 PEO Soldier Control.

This is a measure of the amount of control that PEO Soldier will have over the development of the simulation capability and future modifications. We assumed that, for simulations that already exist, PEO Soldier would have no influence over their development or modification (since this alternative does not include any type of funding by PEO Soldier). Therefore, Janus, JCATS, and OTB all receive a value of 0. For the simulations under development, we assumed that PEO Soldier (again, not funding any of these efforts) may have some input, but very little control, and we therefore scored Cbt^{XXI} and OOS a level of 1. We scored IWARS a level of 2, because that simulation is being designed specifically with support of PEO Soldier's acquisition programs in mind and therefore would give PEO Soldier a larger voice.

Alternatives that include funding will naturally give PEO Soldier more influence over the development of the simulation capability. Thus, PEO Soldier is likely to have some control (corresponding to a level of 4) in alternatives Mod Cbt^{XXI} and Mod OOS, still limited by the fact that these simulation programs encompass a tremendous amount of requirements, of which PEO Soldier's part is small. Mod IWARS, on the other hand, should allow PEO Soldier significant control (a level of 6) since support of organizations like PEO Soldier is the primary purpose of the simulation. In the Combine alternative, PEO Soldier's control over development would still reflect significant control, but not more, thus giving the alternative a level of 6. One might be inclined to reduce the value since it includes two simulations over whose development PEO Soldier would have less control, but the measure reflects control over the development of requirements, not control over a specific program. Finally, if PEO Soldier developed a new simulation, they would have complete control (a level of 10).

3.2.1.7 Fielding Risk.

Fielding risk is a measure of the risk of project failure and ranges in levels from none (0) to very high risk (5). Since existing alternatives are already fielded, there is no fielding risk. Thus, Janus, JCATS, and OTB have levels of 0. We assigned OOS a level of 2 (low risk) because of the amount of resources and effort behind its development. On the other hand, we assigned medium risk (level of 3) to Cbt^{XXI} and IWARS because they receive significantly less levels of funding and have not yet released working models (whereas, at the time of this evaluation, OOS had already released Block B).

With the infusion of resources into any existing developmental effort, we assumed that the risk is reduced to low (a level of 2). Thus Mod Cbt^{XXI}, Mod IWARS, Mod OOS, and Combine all received levels of 2. We did not feel that the amount of resources PEO Soldier might infuse into OOS (which would be a very small percentage of that program's overall budget) would affect its risk rating in this regard. We also rated the Combine alternative at low risk. We scored the development of a new simulation, however, at a level of 4 (high risk) because of the inherent risks of starting a new, long-term venture. PEO Soldier would be competing for the same programming expertise with other, already-established programs. Additionally, while all three simulations under development have received some higher-level support, whether implicit or explicit, any new simulation proposed by PEO Soldier would have to gain such support in an M&S leadership environment leaning towards less, not more, simulations.

3.2.1.8 Time until Available.

This measure has the only natural scale of our eight evaluation measures. As such, this was the most objective (but not without some subjectivity). Since existing simulations are usable now, they were given a value of 0 months. At the time of this evaluation, Cbt^{XXI} was planning a usable release for the Land Warrior (LW) AoA beginning in June, 2005, and thus was 12 months from release. We assumed that IWARS' second release, Version 2.0, with its completed information-centric capability would be the first usable version. Its release was scheduled for the end of FY06, giving it a value of 29 months. However, we have since learned that they have altered their timeline and priority of requirements to have a usable version by June, 2005, for the LW AoA. Nonetheless, we did not learn that information until our evaluation was complete.

OOS' Block D release (what we considered the first usable version for our purposes) was scheduled for the end of FY05, giving it a value of 17 months.

For the modified alternatives – Mod Cbt^{XXI}, Mod IWARS, Mod OOS – we assumed that the timelines would not change with the infusion of PEO Soldier resources, but the requirements might. For the Combine alternative, we used the longest timeline of the three component simulations, or 29 months. Finally, for the New Sim alternative, we used developmental information from CASTFOREM, Combat^{XXI}, IUSS, and IWARS, to estimate the developmental time of a new simulation. We assumed that development would not begin until the new fiscal year (in 5 months) and take approximately 5.5 years to develop – the average of our four estimates – for a total of 71 months.

Chapter 4: Decision Making

4.1 Alternative Scoring.

During this step, we developed value curves that would be used to convert the raw scores determined earlier during modeling for each evaluation measure into value scores (related to, but not the same as, *utility*) on a common scale. That scale ranged from 0 to 100, with 100 being the most desirable. The value curves were based upon the information obtained during our analyses, primarily our stakeholder analysis. For the seven constructed-scale evaluation measures, we chose as the endpoints for our curves the lowest and highest possible levels for that scale. Therefore, the least desirable level on that scale corresponded to a value of 0 and the most desirable level on that scale corresponded to a value of 100. For the one natural measure, *time until available*, we chose 0 months as our 100 value endpoint (since less is better), and 120 months as our 0 value endpoint (since we chose 10 years as our planning horizon).

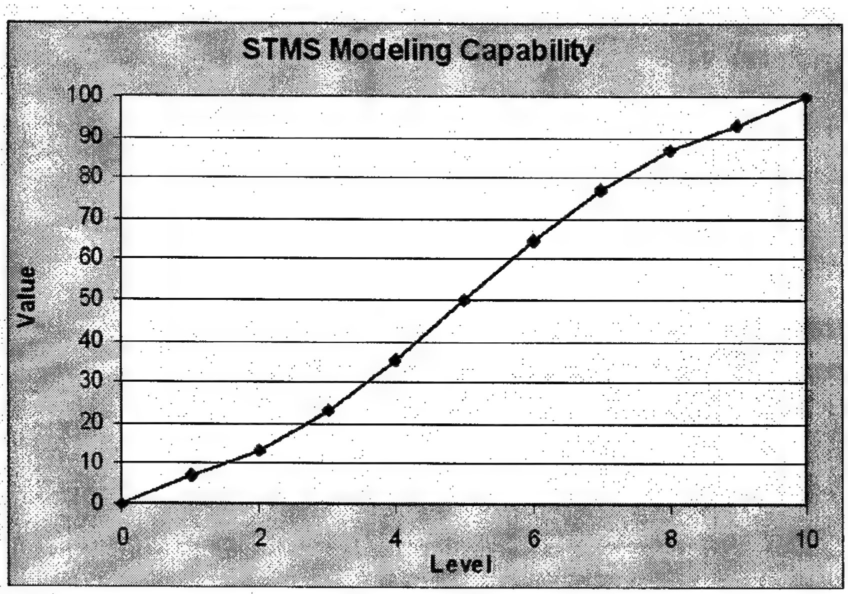

Figure 11. STMS modeling capability value curve.

After determining the endpoints, we used various methods to determine the shape of the curve between the points. The resulting curves took the following shapes: linear, piecewise linear, s-curve, and exponentially increasing. An example is shown in Figure 11 for the evaluation measure *STMS modeling capability*. Based on the slight s-curve shape, we see that

changes in level at the lower and higher ends of the scale are not as valuable as changes in the middle portion of the scale. Similar reasoning, based upon the slope of the curve, can be made for the other curve shapes. Appendix F shows the value curves for all evaluation measures.

After we constructed value scales, we used them to convert the raw data into value scores. We then multiplied the value scores by the global weight of the evaluation measure and summed the result for all evaluation measures to obtain a total value score for each alternative. The decision matrix (DM) in Table 5 summarizes the conversion to value scores and the resulting total value scores for each alternative. The number listed for each alternative and evaluation measure corresponds to a value score. The numbers in the bottom row correspond to the total value scores for the alternatives (value scores multiplied by the global weights and summed for that column).

	Global Weight	Janus	JCATS	OTB	Cbt XXI	IWARS	OOS	Mod Cbt XXI	Mod IWARS	Mod OOS	Combine	New Sim
Joint/CA Modeling Capability	0.150	50	60	60	60	40	70	70	50	80	90	100
STMS Modeling Capability	0.245	6.9	22.9	22.9	35.6	77.1	50	50	86.7	64.4	93.1	100
Modifiable Equipment Types	0.035	25	36	36	49	64	49	64	81	64	81	100
User Control Over Conditions	0.035	69	69.1	69	84	84.1	84.1	93.3	93.3	93.3	97.7	100
TTP Modifiability	0.035	20	20	50	100	100	100	100	100	100	100	100
PEO Soldier Control	0.150	0	0	0	17.5	35	17.5	70	80	70	80	100
Fielding Risk	0.150	100	100	100	50	50	70	70	70	70	70	10
Time Until Available	0.200	100	100	100	95.7	81.6	92.3	95.7	81.6	92.3	81.6	43.9
Total Value Score		**48.2**	**54.0**	**55.1**	**55.1**	**62.6**	**62.5**	**71.9**	**77.1**	**76.3**	**84.9**	**75.3**

Table 5. Decision matrix (DM).

4.2 Decision.

4.2.1. Alternative Comparison.

By looking at the decision matrix in Table 5, the reader can see that the alternative with the highest total value score is Combine – the modification of and linkage between Combat^{XXI}, IWARS, and OOS. The next four scores (Modified IWARS, Modified OOS, New Simulation, and Modified Combat^{XXI}) are grouped fairly close together, but significantly behind that of Combine. Although we mentioned it earlier in the paper during modeling, it is important to point out again that these scores meaning nothing in isolation. They are a means to compare the value of the alternatives in terms of the stakeholders' objectives, on a *relative* basis. Thus, Combine, relative to the other alternatives, best meets the objectives of the stakeholders. Figure 12 and

Figure 13 below show stacked bar graphs of the value scores within each of the two primary subfunctions: *simulate* and *support decision-making* functions respectively.

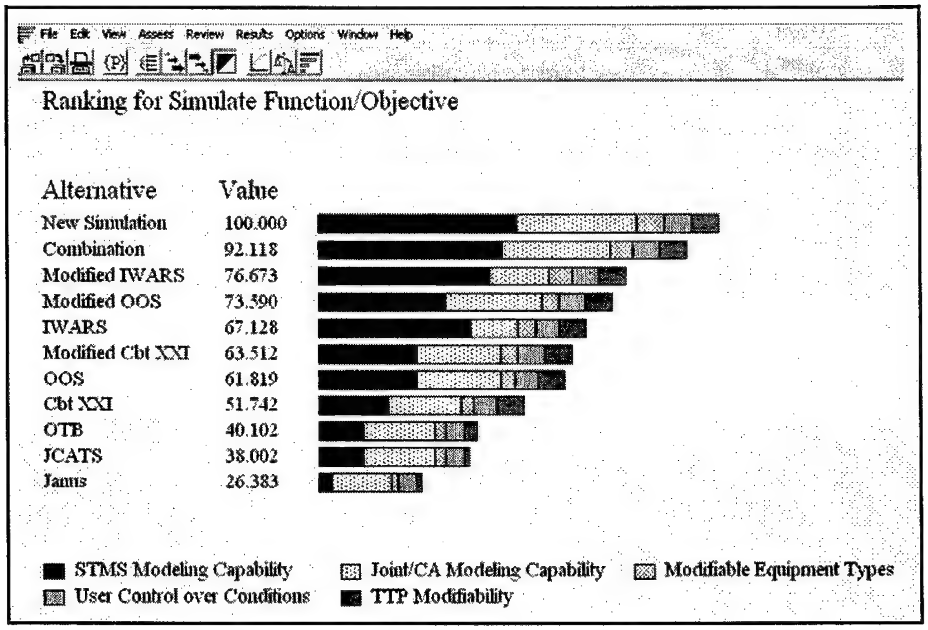

Figure 12. Stacked bar graph of the value scores within the simulate function.

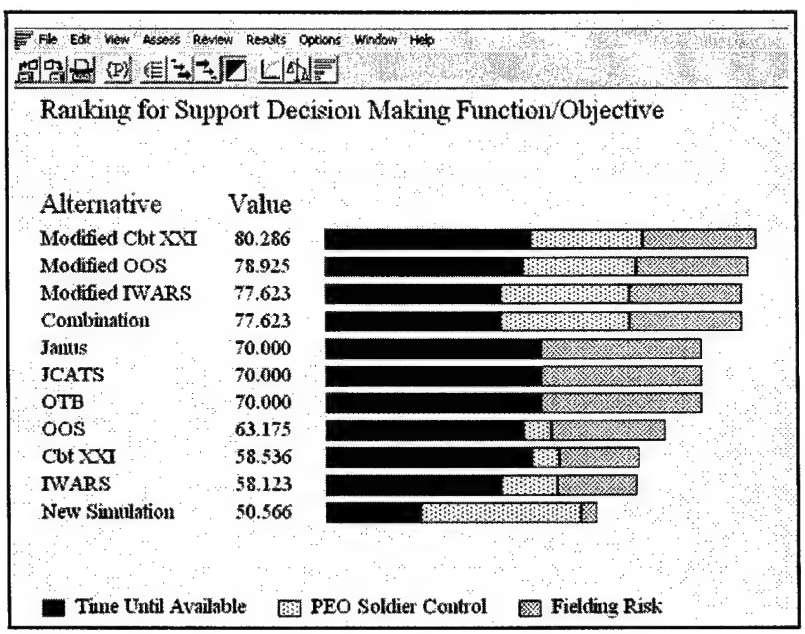

Figure 13. Stacked bar graph of the value scores within the support decision making function.

As one would expect, New Sim scores the highest within the *simulate* function; however, it scores the lowest within the *support decision-making* function. The graphs above also show the contribution of each of the evaluation measures to its parent function.

4.2.2. Sensitivity Analysis.

Much of the process that led to the total value scores (weighting, modeling, and value conversions) was subjective. Therefore, we conducted sensitivity analysis on our results to determine if our best alternative would be different given small changes to the subjective ratings.

4.2.2.1 Sensitivity of the Weights.

First, we looked at the weighting assigned to each of the evaluation measures. Figure 14 below is a screen shot from *Logical Decision for Windows* showing the sensitivity of the total value scores to the global weight of the *STMS modeling capability* evaluation measure.

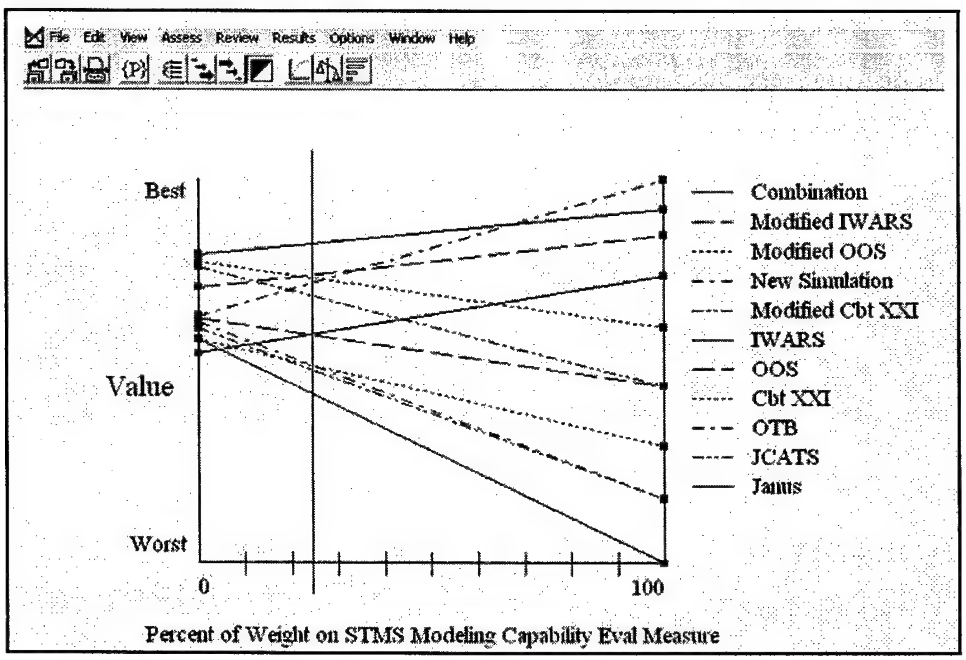

Figure 14. Graph of the sensitivity of the global weight of STMS modeling capability.

The y-axis represents total value score and the x-axis represents the global weight of the evaluation measure. Each line in the graph represents an alternative. The vertical line indicates the original global weight of the evaluation measure (in this case, 0.245). At the original global weight, the reader can see that the best alternative (highest line) is the Combine alternative. By moving along the line representing the best alternative, one can find the point (point of

indifference) at which another alternative scores a higher total value score. In this case, at a global weight of about 0.68, the New Sim alternative becomes the highest scoring. Thus, the client would have to shift his global weight of this measure to 0.68 for our recommended alternative to change. The rule of thumb we used for such analysis is that a point of indifference within 0.1 of the original global weight indicates sensitivity of our alternative to the global weight of that evaluation measure. We constructed such graphs for all eight evaluation measures (refer to Appendix G) and found that our alternative was not sensitive to the global weighting of any of the evaluation measures.

4.2.2.2 Sensitivity of the Alternative Modeling.

We also looked at the sensitivity of the scores we assigned to the alternatives for each of the evaluation measures during our modeling step. For this, we first eliminated six of the alternatives from consideration (Janus, JCATS, OTB, Cbt^{XXI}, IWARS, and OOS) using the following analysis. We assumed that all of the scores we assigned to these six alternatives were underestimates and we therefore raised or lowered them (depending on which level was more preferable) one level for all relevant evaluation measures. Even with this, the highest scoring of the six alternatives fell 10 points below the Combine alternative. Since their total value scores were still significantly lower than our recommended alternative's total value, we determined that no changes, within realistic bounds, to the scores we assigned them would cause any of them to be the highest scoring alternative.

That left five alternatives to analyze. We had already assigned the highest possible levels to the New Sim alternative for all but two of the measures – *fielding risk* and *time until available*. Even when we reduced the *fielding risk* to medium and the *time until available* by a year, New Sim still fell slightly behind the Combine alternative, although by only just over a point. However, we were fairly confident in the values we assigned originally for the two measures. The remaining three alternatives that scored below the Combine alternative were Mod IWARS, Mod OOS, and Mod Cbt^{XXI}. Since the Combine alternative includes the modification of those three simulations already, we determined that, at worst, it would score the same as those three alternatives for the five measures under the *simulate* function. We applied similar reasoning for the three measures under the *support decision-making* function. Only the *time until available* measure seemed to have the potential for a lower score (more time) than the other three. On the

other hand, by using all three simulations in the Combine alternative, we could assume that PEO Soldier would be increasing their *control* over the solution (by shifting requirements between the simulations) and reducing their *fielding risk* (by not putting all of their resources into a single simulation).

As a result of the above analysis, we determined that the recommended solution was not sensitive to the scores we assigned during modeling (assuming realistic bounds on those scores).

4.2.2.3 Sensitivity of the Value Curves.

Our final sensitivity analysis involved the value curves. To test the sensitivity of the value curves, we decided to see if the recommended alternative would change if all of the value curves were linear (versus piecewise linear, s-curve, or increasing exponential). Figure 15 shows the resulting total value scores with linear value curves. The difference in total value scores between Combine and the three modification alternatives actually increases slightly. On the other hand, the difference between Combine and New Sim decreases to less than 2 points. However, the recommended alternative still does not change. Therefore, we determined that the recommendation is not sensitive to the value curves.

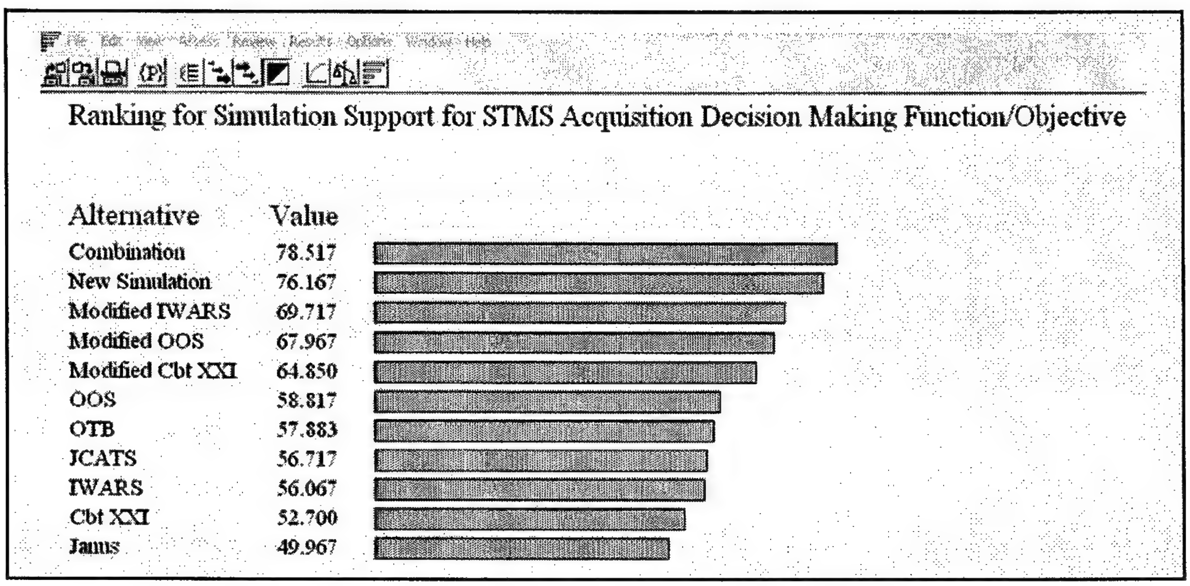

Figure 15. Total value scores assuming linear value curves.

4.2.3. Cost-benefit Analysis.

We did not account for total cost in our value hierarchy because we treat cost as an independent variable. Therefore, after conducting sensitivity analyses, we conducted a cost-benefit analysis. Similar to what we faced with our other modeling, the determination of costs for alternatives that are still under development or not in existence was imprecise, at best. We did not have the detailed information necessary to determine the cost of modifications, since those costs would depend greatly on which requirements needed to be added to the simulation(s) and how hard the integration of those requirements would be. Therefore, we used the information we had available to be within order-of-magnitude accuracy. Our detailed cost estimations can be found in Appendix G. Figure 16 shows the resulting cost-benefit graph. Since creating a new simulation was both orders-of-magnitude more costly and provided less benefit, it was dominated by the highest-scoring alternative.

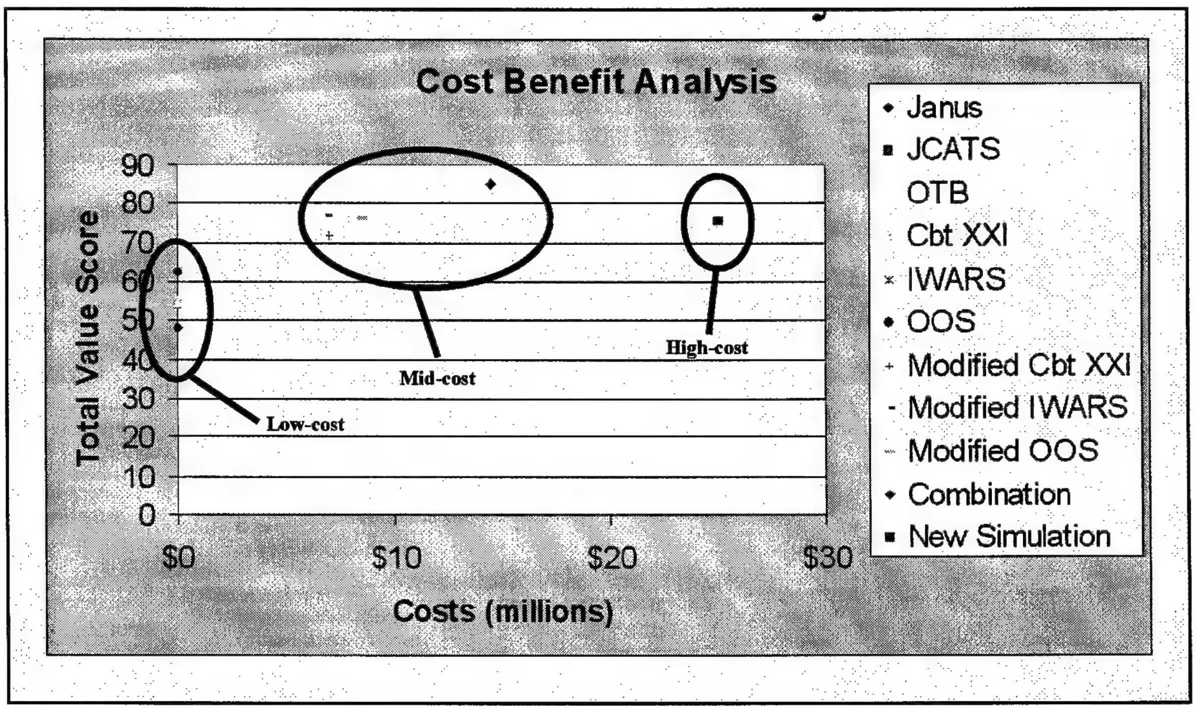

Figure 16. Cost-benefit graph.

Our analysis can also be viewed by cost groupings. In that view, the alternatives generally fell into three groups: low-cost (existing simulations and simulations under development), mid-cost (modifying and/or combining existing simulations and simulations under development), and high-cost (developing a new simulation). The groups are labeled in Figure

16. Again, creating a new simulation was both more costly than any member of the mid-cost group and still provided less benefit than the highest-scoring alternative. Also, since the Combine alternative fell within the same cost category of the closest-scoring alternatives, it could not be ruled out due to costs. Thus, the Combine alternative remained our recommended solution.

4.2.4. Recommendation.

We presented our results and recommendation to our client, PEO Soldier, on 14 May 2004. They agreed with our recommendation and have begun to process of generating community buy-in and implementing the solution.

It is important to note that we are not recommending that PEO Soldier and those conducting analyses on their products cease to use other simulations. In the short term, we must continue to use tools that are currently in existence, many of which have tremendous strengths and capabilities. In fact, even after this recommendation comes to fruition, there may very well be appropriate times to use other simulations to conduct analyses within certain niches where their strengths lie. However, as far as the investment of PEO Soldier resources to solve this particular problem in the long-term, we make the above recommendation.

Chapter 5: Implementation

5.1 Planning for Action.

We are now in the process of conducting joint presentations with PEO Soldier to selected major players in the DoD analysis and Infantry soldier system acquisition communities. These presentations will explain our methodology, results, and recommended course of action. Such meetings will ensure that key members of the community understand PEO Soldier's needs and how those needs are met by modifying and combining Combat^{XXI}, IWARS, and OOS. Additionally, we can consider and integrate suggestions from others who may have important insights into the problem and the solution.

Once we have consensus in the community, we will move forward with implementation. The first primary task that we must accomplish is to establish points of contact (POCs) and/or liaisons with each of the simulation proponents in order to open lines of communication and to facilitate the flow of information. From there, we can begin to negotiate agreements between PEO Soldier and the simulation proponents. While such negotiations can begin in generalities, we will need to move rapidly into specifics in order to move forward with the implementation. Therefore, we must begin the process of converting our functional requirements into simulation specifications that will allow simulation managers and programmers to implement PEO Soldier requirements into their software. Integral to that process is determining how to divide the requirements among the simulations either through direct modification or through a linkage. Factors that might affect this parsing of requirements, especially in cases where more than one option exists, include the planned and existing capabilities of the simulations, simulation architectures, cost of implementing the requirement, usefulness to the simulation proponent, basis for the requirement, implementation time, and synergy with other requirements. Thus, we must attempt to optimize the benefit by minimizing the costs, both financial and other.

5.2 Execution.

With the initial agreements complete, a set of specifications, a comprehensive plan to implement those specifications, and initial timelines, costs, and resources determined, we will begin execution of our recommendation. During this step, simulation proponents will integrate

PEO Soldier requirements into their software and develop architectures and interfaces that will facilitate the linkages required for successful implementation of the solution.

5.3 Assessment and Control.

Our role during implementation (after the planning step is complete) will primarily shift to that of monitoring progress, renegotiating agreements due to unexpected changes, quality assessment, and supervising VV&A. Our responsibility will be to ensure that not only are the requirements met, but that those requirements remain valid and updated to reflect PEO Soldier's evolving needs.

Chapter 6: Conclusions

PEO Soldier approached us with a challenging problem and a short suspense. Nonetheless, our application of a systematic systems engineering approach provided us the tools necessary to conduct a thorough analysis in a relatively short period of time. As a result, we were able to present a robust recommendation that PEO Soldier has accepted and begun to implement. The modification of and linkage between Combat^{XXI}, the Infantry Warrior Simulation (IWARS), and Objective One Semi-Automated Forces (OOS) offers the greatest benefit in terms of simulation capability and decision support.

Each simulation has unique strengths that, when combined, should have great synergistic effects on the resulting federation. IWARS will have tremendous strengths in terms of individual soldier modeling, whereas OOS and Combat^{XXI} will have robust combined arms representations. Combat^{XXI} will provide great analytical capability as a closed-loop simulation, whereas OOS' greatest strength will be in HITL. IWARS, designed for both types of human interaction, will be able to link to both by operating in either mode. OOS' environmental runtime component, being used by all three simulations, will facilitate a detailed representation of the environment. By being able to link to OOS, Combat^{XXI} and IWARS will benefit from the numerous concurrent efforts being conducted to support OOS, such as the work of the UO FACT. Thus, where one simulation may have weaknesses, another simulation has strengths.

Finally, PEO Soldier support for efforts already underway conserves scarce resources and leverages valuable work already invested. Their support benefits the simulation proponents, as well, by adding value to their efforts and expanding their application areas. Clearly, this recommendation will benefit all involved.

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Appendix A: List of Abbreviations

2D	2-Dimensional
3D	3-Dimensional
A	
ABM	Agent-Based Model
ACR	Advanced Concepts and Requirements
ACTD	Advanced Concept Technology Demonstration
AI	Artificial Intelligence
AIMS	AMSAA Infantry MOUT Simulation
AMSAA	U.S. Army Materiel Systems Analysis Activity
AMSO	Army Model and Simulation Office
AoA	Analysis of Alternatives
API	Application Programming Interface
AR	Army Regulation
ARL	Army Research Lab
ATD	Advanced Technology Demonstration
AUTL	Army Universal Task List
AWARS	Advanced Warfare Simulation
AWE	Advanced Warfighting Experiment
B	
BCT	Brigade Combat Team
BG	Brigadier General
BIF	Battlefield Information System
BLOS	Beyond Line of Sight
BOI	Basis of Issue
BOS	Battlefield Operating System
C	
C2	Command and Control
C4ISR	Command, Control, Computers, Communication, Intelligence, Surveillance, and Reconnaissance
CA	Combined Arms
CAD	Computer-Aided Design
CAS	Close Air Support
CASTFOREM	Combined Arms and Support Task Force Evaluation Model
CDA	Commander's Digital Assistant
CDD	Capability Development Document
CJCSI	Chairman of the Joint Chiefs of Staff Instruction
CJCSM	Chairman of the Joint Chiefs of Staff Manual
CM	Configuration Management
COL	Colonel
Combat^{XXI}	Combined Arms Analysis Tool for the XXIst Century
COP	Common Operating Picture
CPD	Capability Production Document

CPT	Captain
CPU	Central Processing Unit
CRD	Capstone Requirements Document
D	
DA	Department of the Army
DIS	Distributed Interactive Simulation
DISAF	Dismounted Infantry Semi-Automated Forces
DM	Decision Matrix
DMSO	Defense Model and Simulation Office
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DOTLMPF	Doctrine, Organization, Training, Leadership, Materiel, Personnel, and Facilities
DTIC	Defense Technical Information Center
DUSA(OR)	Deputy Under Secretary of the Army for Operations Research
E	
EPS	Engineering Problem Statement
F	
FAA	Functional Area Analysis
FACT	Focus Area Collaborative Team
FFW	Future Force Warrior
FM	Field Manual
FNA	Functional Needs Analysis
FOC	Force Operating Capabilities
FSA	Functional Solution Analysis
FY	Fiscal Year
G	
GUI	Graphical User Interface
GW	Global Weight
H	
HBR	Human Behavior Representation
HITL	Human in the Loop
HLA	High Level Architecture
HMD	Helmet Mounted Display
I	
ICD	Initial Capabilities Document
ICT	Integrated Concept Teams
IDEF	Integration Definition for Function Modeling
IO Device	Input-Output Device
IPR	Interim Progress Report
IR	Infrared
IT	Information Technology
I/ITSEC	Interservice/Industry Training, Simulation and Education Conference
IUSS	Integrated Unit Simulation System

IWARS	Infantry Warrior Simulation
J	
JCATS	Joint Conflict and Tactical Simulation
JCIDS	Joint Capabilities Integration and Development System
JUTL	Joint Universal Task List
K	
L	
LLNL	Lawrence Livermore National Laboratories
LOS	Line of Sight
LTC	Lieutenant Colonel
LW	Land Warrior
LW	Local Weight
M	
M & S	Modeling and Simulation
MAJ	Major
MATREX	Modeling Architecture for Technology, Research and Experimentation
MAWG	Modeling and Analysis Working Group
METT-TC	Mission, Enemy situation, Terrain, Troops available, Time available, Civil considerations
MNS	Mission Need Statement
MOA	Memorandum of Agreement
MoE	Measure of Effectiveness
MoM	Measure of Merit
MoP	Measure of Performance
MOU	Memorandum of Understanding
MOUT	Military Operations in Urban Terrain (now Urban Operations)
MS	Milestone
N	
NATO	North Atlantic Treaty Organization
NGF	Naval Gunfire
NLOS	Non-line of Sight
NSC	Natick Soldier Center
NSC	National Simulation Center
O	
OFW	Objective Force Warrior (now Future Force Warrior)
OOS	Objective OneSAF
OOTW	Operation Other Than War
ORCEN	Operations Research Center of Excellence
ORD	Operational Requirements Document
ORSA	Operations Research / Systems Analysis
OTB	OneSAF Testbed Baseline
P	
PEO	Program Executive Office
PEO STRI	PEO for Simulation, Training, and Instrumentation

PM-CIE	Product Manager – Clothing and Individual Equipment
PM-LW	Product Manager – Land Warrior
PM-OneSAF	Product Manager – OneSAF
PM-SW	Project Manager – Soldier Weapons
PM-SWAR	Project Manager – Solder Warrior
POC	Point of Contact
Q	
R	
RDA	Research, Development, and Acquisition
RDEC	Research and Development Engineering Center
RDM	Raw Data Matrix
ROE	Rules of Engagement
S	
SA	Situational Awareness
SAF	Semi-Automated Forces
SAG	Study Advisory Group
SASO	Stability and Support Operations
SBA	Simulation Based Acquisition
SBL	Soldier Battle Lab
SE	Systems Engineering
SEMP	Systems Engineering and Management Process
SES	Senior Executive Service
SMART	Simulation and Modeling for Acquisition, Requirements, and Training
SME	Subject Matter Expert
SSE	Squad Synthetic Environment
SSP	Simulation Support Plan
S&T	Science and Technology
STMS	Soldier Tactical Mission System
STO	Science and Technology Objective
SU	Situational Understanding
T	
T&E	Test and Evaluation
TEMO	Training, Exercises, and Military Operations
TEMP	Test and Evaluation Master Plan
TPIO	TRADOC Program Integration Office
TPO	TRADOC Project Office
TRAC	TRADOC Analysis Center
TRAC-FLVN	TRAC at Fort Leavenworth, KS
TRAC-MTRY	TRAC at Monterey, CA
TRAC-WSMR	TRAC at White Sands Missile Range, NM
TRADOC	Training and Doctrine Command
TSM	TRADOC System Manager
TTP	Tactics, Techniques, and Procedures
U	

UA	Unit of Action (now Brigade Combat Team)
UAV	Unmanned Aerial Vehicle
UE	Unit of Employment
UGS	Unattended Ground Sensor
UGV	Unattended Ground Vehicle
UO	Urban Operations
USAIC	US Army Infantry Center
USMA	United States Military Academy
V	
VIC	Vector in Commander
VV&A	Verification, Validation, and Accreditation
W	
WSC	Winter Simulation Conference
XYZ	

*This table is sorted alphabetically

Appendix B: Soldier Functional Hierarchy

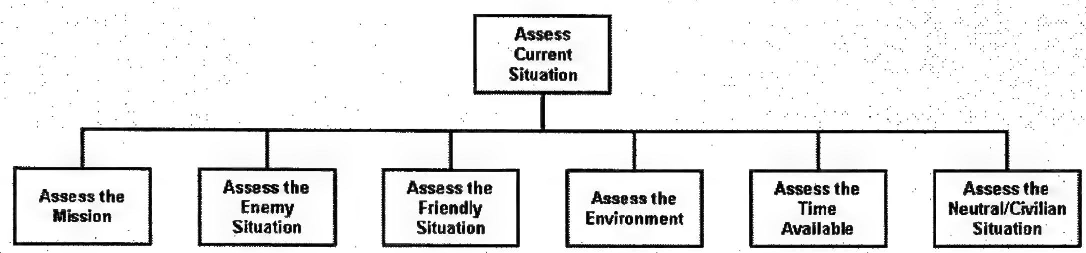

Figure 17. Functional decomposition of assessing the situation.

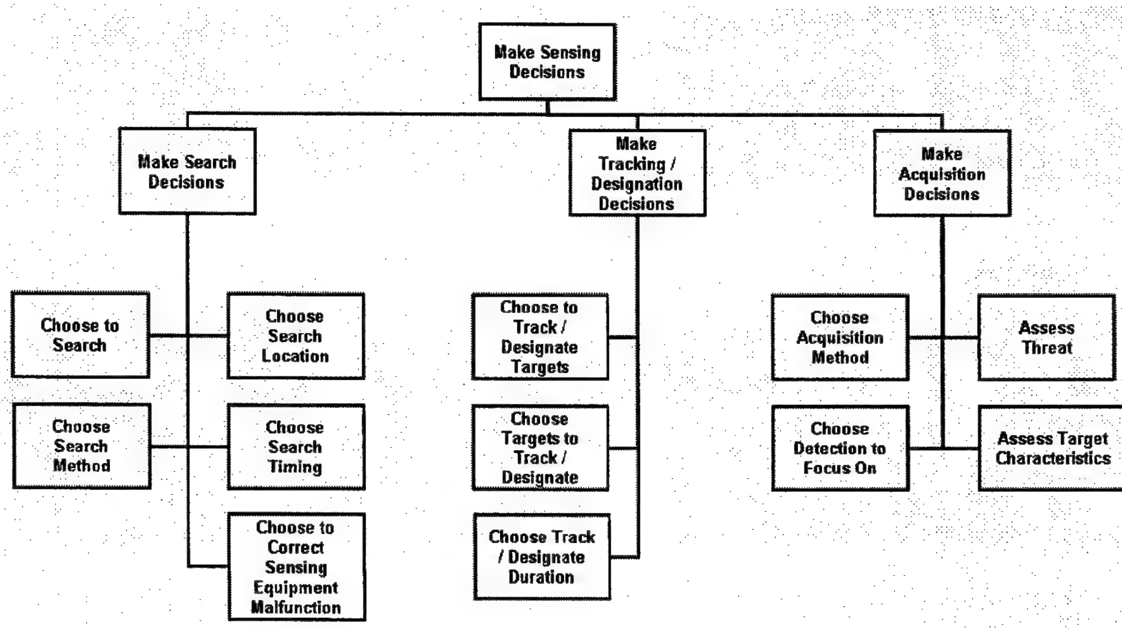

Figure 18. Functional decomposition of making sensing decisions.

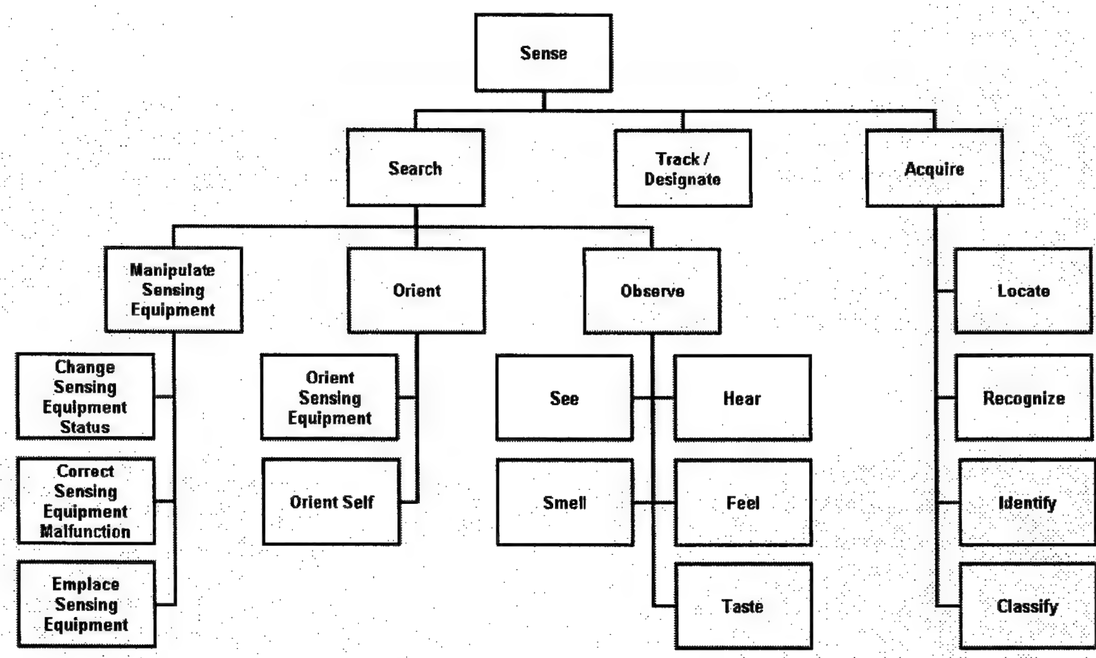

Figure 19. Functional decomposition of sensing.

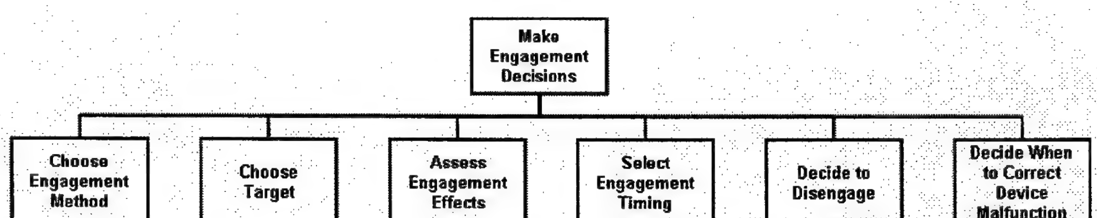

Figure 20. Functional decomposition of making engagement decisions.

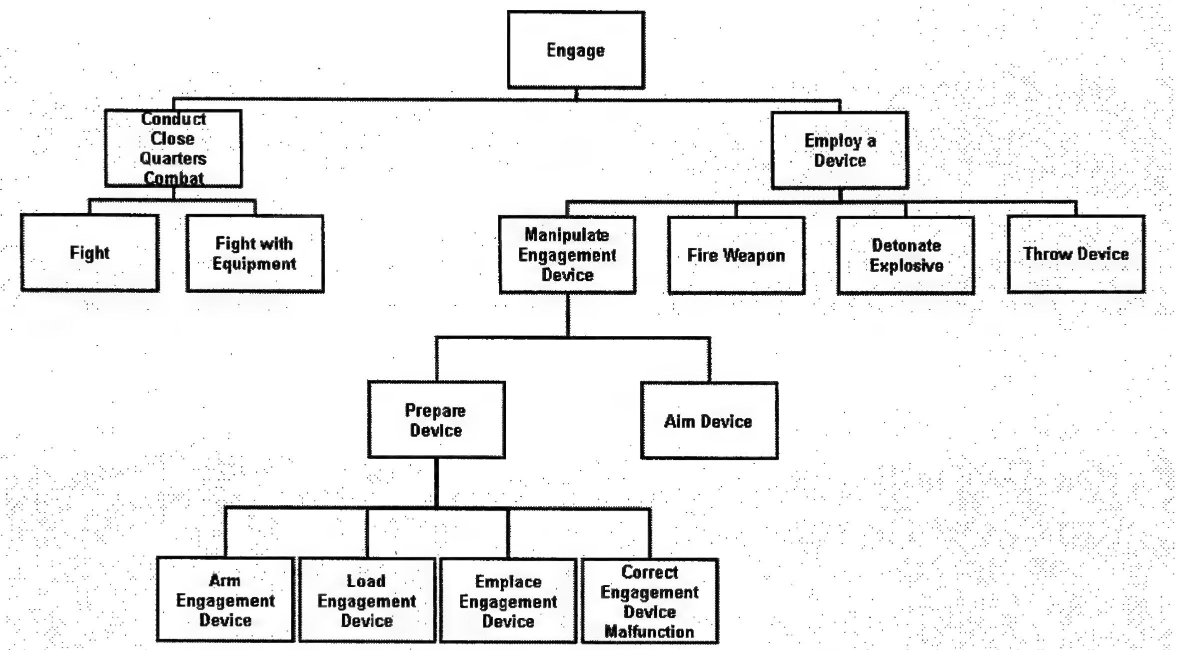

Figure 21. Functional decomposition of engaging.

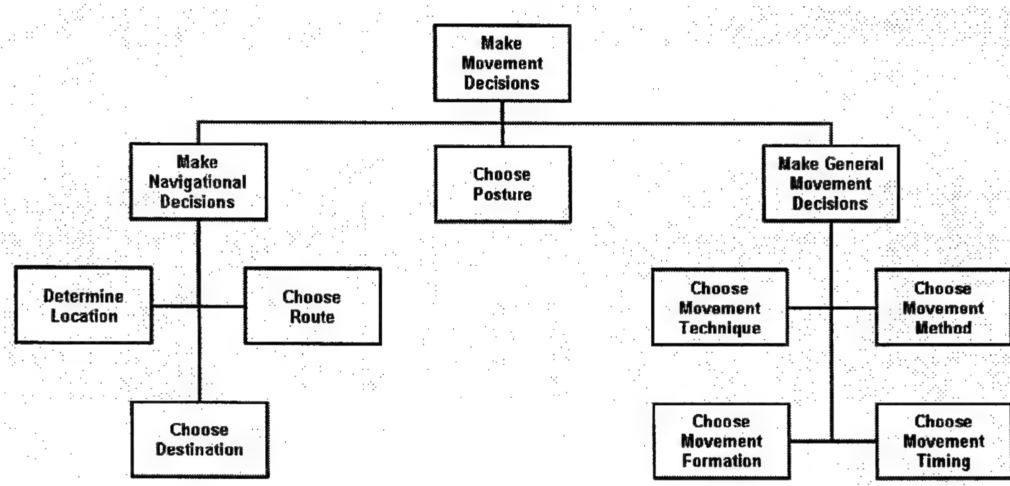

Figure 22. Functional decomposition of making movement decisions.

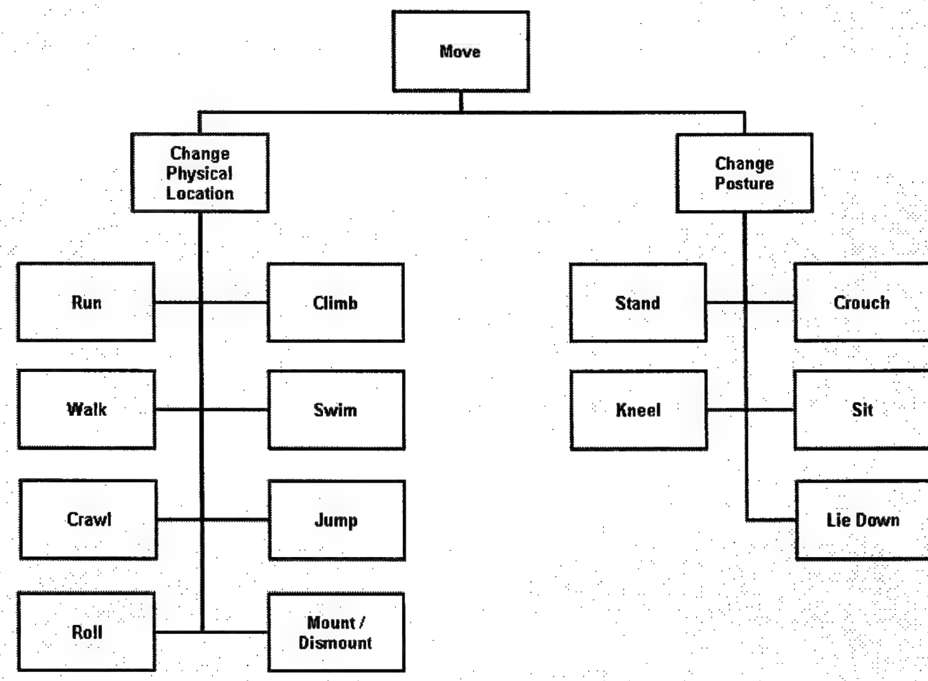

Figure 23. Functional decomposition of moving.

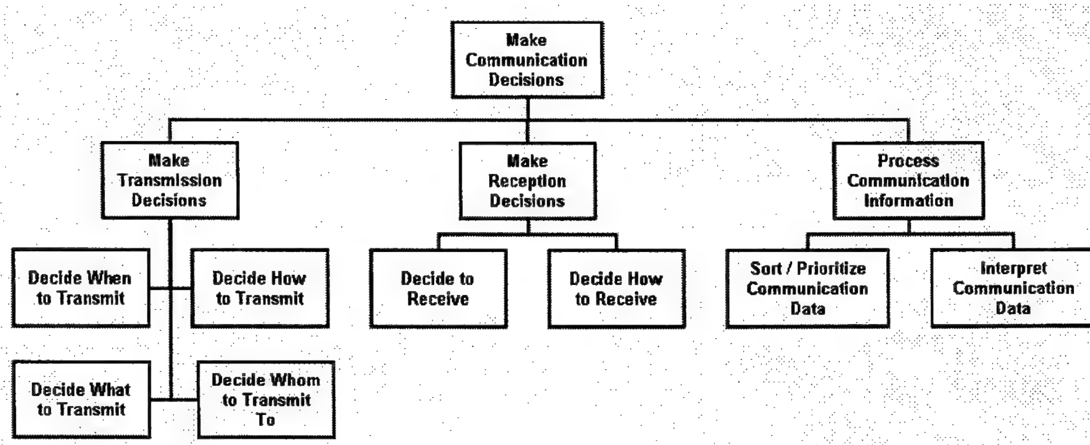

Figure 24. Functional decomposition of making communications decisions.

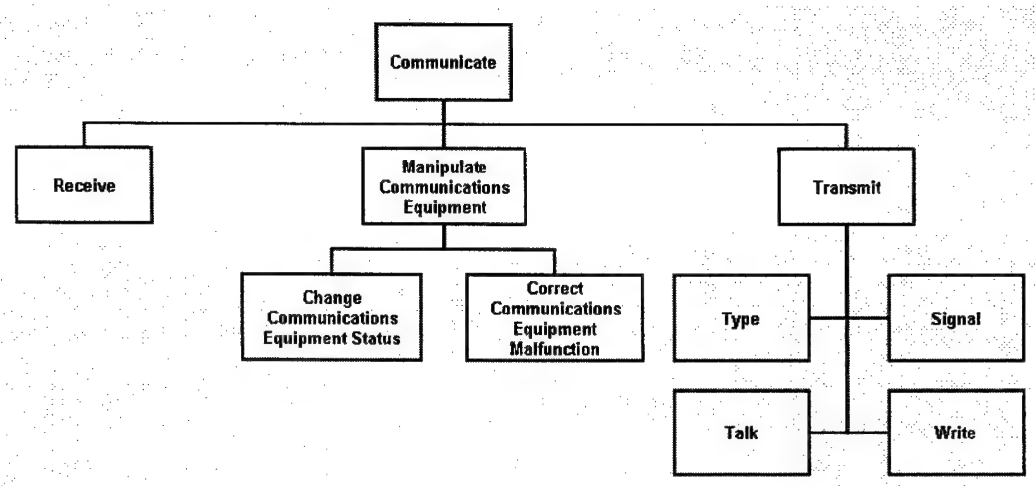

Figure 25. Functional decomposition of communicating.

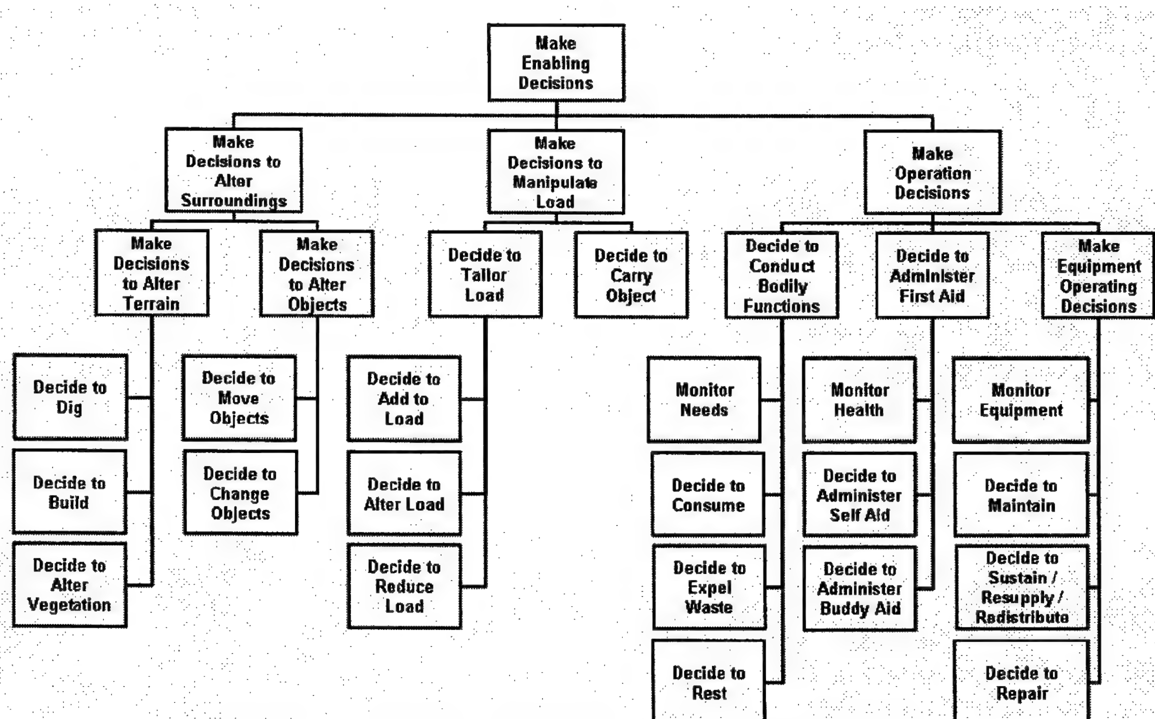

Figure 26. Functional decomposition of making enabling decisions.

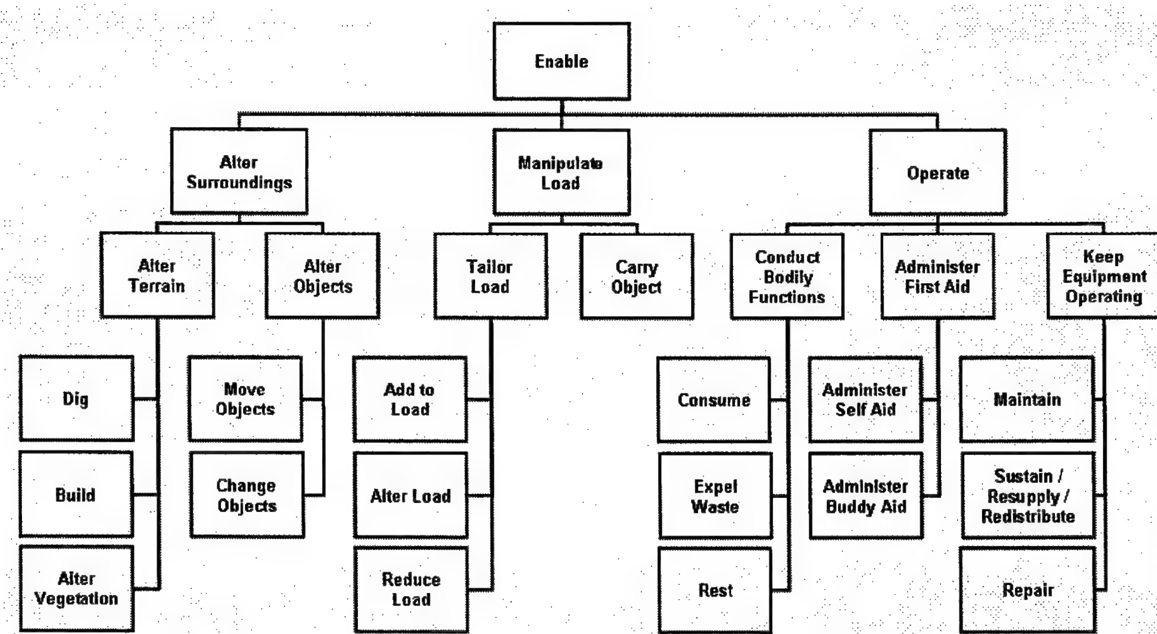

Figure 27. Functional decomposition of enabling.

Appendix C: STMS Simulation Functional Requirements

Functional Requirements
for a
Soldier Tactical Mission System (STMS)
Simulation Capability

Version 0.3

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14 May 2004

I. INTRODUCTION.

This document outlines the key functional requirements for a simulation capability that a Soldier tactical mission system (STMS) acquirer, particularly the Program Executive Office Soldier (PEO Soldier), can use for analytical purposes. Specifically, these requirements are meant to satisfy the following problem statement:

> Identify or develop a tactical combat simulation capability for Light Infantry missions at the level of Platoon and below with resolution down to the individual Soldier. The simulation must accept, as input, scenarios and Soldier tactical mission system (STMS) characteristics. It must model the functions of the Soldier in a tactical environment, and provide, as output, the measures of effectiveness (MOEs) used to evaluate STMS mission effectiveness. It must be adaptable to changes in technology and operational environments. The simulation(s) will provide the analytical capability to support Program Executive Office (PEO) Soldier decision making.

This document is not intended to be a "requirements document" in the sense of an operational requirements document (ORD) or a set of specifications for contracting. Instead, it delineates the key characteristics of the simulation software and modeling aspects that would make a simulation (or family of simulations) ideal for PEO Soldier decision-making.

We have based the information contained here upon interviews, visits to organizations throughout the Army, and literature reviews. While we consider our research representative of the domain, it is, by no means, completely exhaustive. Therefore, this document is, and should remain, a working document that PEO Soldier, or that organization's designated representative, updates when new information becomes available.

II. METHODOLOGY.

Our decomposition of simulation requirements is unique in that we decomposed by soldier function. The normal approach for identifying simulation requirements for analytical purposes is to categorize them by the characteristics used to evaluate the system of interest. For instance, the effectiveness of an STMS is measured by its lethality, survivability, mobility, situational awareness, etc. Although we initially chose to use this method, we switched to a functional decomposition for a number of reasons. One is that the characteristic itself may not be well-defined or translate well into simulation requirements – for example, situational awareness. Not only is the definition of this term not widely agreed upon, its broad implications make it hard to decompose into requirements. A soldier's situational awareness directly affects, and is directly affected by, other characteristics like mobility, lethality, and survivability, which themselves overlap for many of the soldier's functions. That interdependence complicates the logical decomposition into simulation requirements and is the primary reason we chose another method. Even more, the diverse group of simulation stakeholders may not easily understand the terminology of the resulting product. Therefore, we looked at the functions (and indirectly at tasks) that an Infantry soldier must perform on the battlefield to accomplish his mission successfully.

We identified the primary soldier functions and decomposed each of those. We decomposed down to subfunctions that either affect the performance of the soldier system or component, or allow for differentiation between alternative systems, making sure we considered current and future systems. This technique allowed us to focus on representations that are important for acquisition decision-making, versus training or mission rehearsal. For each of the lowest level functions, we have identified the inputs and outputs critical for each of the subfunctions. The simulation, then, must model those inputs and outputs to assess accurately the performance of an STMS.

III. OUTPUTS.

As a result of the approach discussed above, this document is organized first by simulation function, and then by soldier function. Some areas warrant additional discussion and are included as separate sections as well. For the general simulation functions, we identify the key characteristics required for an ideal simulation. For each of the lowest-level Soldier functions, those inputs transformed by, and outputs produced by, those functions most critical for evaluating STMS are listed. As previously mentioned, the inputs and outputs are not exhaustive and should be updated as needed.

IV. ADDITIONAL NOTES.

A. We use the term "simulation" to mean either a single simulation or a linkage of two or more. The linkage may be direct, through architecture (HLA, MATREX), or through data exchange. We are identifying requirements for a simulation capability without attempting to define how that might be accomplished.

B. This document identifies the required capabilities (both current and projected for use with future materiel acquisition) of the ideal simulation. We include information regardless of whether or not the current technology, state of knowledge, and/or data exist to support its development.

C. These requirements contain many lists of examples. Before conversion to simulation specifications, these must be converted to definitive lists based upon the intent of the sponsoring organization(s).

D. To the extent possible, we have tried to list functions in a logical order for flow purposes. However, in some cases, outputs of functions listed may be inputs to functions already discussed. We have tried to ensure that all functional outputs are inputs into other functions, and vice versa. The exceptions, of course, are those inputs from, and outputs into, the environment.

E. Even if valid algorithms and techniques can be created for all required capabilities, there are significant gaps in the required data. Such gaps will prevent the attainment of a good model, if not addressed. This document can be used to identify data shortcomings and to focus future data collection efforts.

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I. GENERAL SIMULATION FUNCTIONS

The model we used for the initial decomposition of the required simulation functions is from Hatley and Pirbhai's architectural template in Figure 28. Their architecture is a generic template for decomposing the functions of a system for purposes of system specification (Hatley and Pirbhai, 1988). This model provides us with a logical functional grouping to organize the upper level simulation requirements.

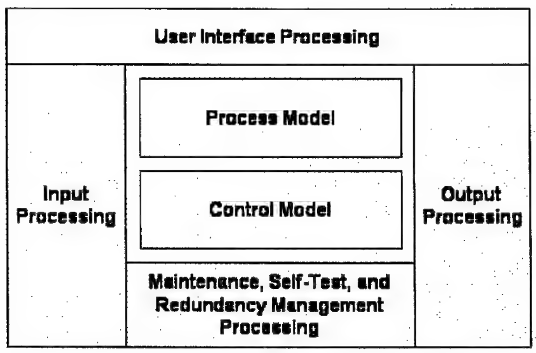

Figure 28. Hatley and Pirbhai architecture template (1998).

A. Interface with User. This function has to do with obtaining information from the user, giving the user feedback on the inputs received, presenting the outputs of the simulation to the user, requesting information from the user, and providing a means for the user to request information from the simulation.
The following are simulation requirements that relate to this function:

- Intuitive (Windows-like; menu driven)
- Understandable to subject matter experts, users, and analysts
- Allows the input of new equipment and weapons systems through changes to parameters; parameters must be robust enough to encompass the largest possible array of potential weapons and equipment
- Allows the user or analyst to alter behaviors/TTPs
- Intuitive scenario development (use of Army operational terms and symbols and other recognizable icons)
- Input configuration reflects military decision making
- Allows for multiple input methods
- Allows the reuse of previous scenarios and annotated terrain as a starting point for developing new scenarios
- Allows the extraction of stored data during any point of the scenario execution
- Visual output and playback capability to allow for face validation of models and scenarios, as well as a qualitative handle on the results

B. Process Inputs. This function concerns the conversion of inputs from external interfaces and other components of the simulation into data usable by the simulation for processing.
The following are simulation requirements that relate to this function:

- Can interface with other simulation systems through HLA or other federation simulation architectures (e.g., MATREX)

- Identification of internal data errors relayed to the user through the user interface; easy-to-follow audit trail
- Managed internal data conversion process
- Able to input data from other sources (external database, spreadsheet, engineering simulation output, etc)

C. Control Processes. This function has to do with the control of the simulation processing itself and would manage such processes as timing and linkages to higher fidelity models. The following are simulation requirements that relate to this function:

- HLA compliance
- Flexible; plug-and-play backbone that allows integration of additional capabilities
- Object-oriented coding
- Configuration managed by a plan
- Constructive simulation – non human-in-the-loop (HITL), but allows for HITL execution, if desired
- Stochastic repeatability (same inputs with the same random seed produces the same outputs)
- Fidelity control (ability to use higher fidelity models if necessary or to use aggregated results in lieu of those models)
- Preprocessing capability to reduce runtime
- Minimize runtime
- Operate with unclassified and classified data

D. Process Model. This function has to do with the actual simulation model itself and how it processes the user inputs into outputs. The discussion of the simulation model will occur later in the sections describing Non-Soldier Representation, Soldier Attributes, and Soldier Representation.

The following are general simulation requirements that relate to this function:

- Has both high-fidelity models and aggregated results of those models to be drawn upon as needed
- Verified, validated, and accredited for its intended uses

E. Process Outputs. This function concerns the conversion of simulation outputs into data usable by external interfaces and other components of the simulation.

The following are simulation requirements that relate to this function:

- Exportable outputs to commercial statistical and graphical software
- Identification of internal data errors relayed to the user through the user interface
- Managed internal data conversion process
- Continuous or event-driven output capability

F. Maintain, Self-Test, and Manage Redundancy. These functions have to do with diagnostic testing, internal simulation monitoring, error detection, and the ability to draw on redundant resources.

The following are simulation requirements that relate to this function:

- Capable of debugging changes to code

- Clear identification and presentation of errors
- Traceability – audit trail to identify sources of error
- Data backup capability to avoid catastrophic loss of data

G. Other.

- Includes, at a minimum, the following types of documentation guides: user, methodology, and analyst. They can be rolled up into one document, but should address the topics unique to each type.
- Includes a complete verification, validation, and accreditation (VV&A) plan and documentation.

II. SIMULATION SCENARIOS

We believe that the level of fidelity required by the simulation, as we delineate it in this document, is sufficient to ensure that any potential scenario can be modeled. Therefore, we will only briefly discuss the points below.

To understand best what future operations the Army may encounter, we can refer to FM 7-15, *The Army Universal Task List* (AUTL). The four main types of Army operations are offensive, defensive, stability, and support operations. Refer to Annex A for a complete breakdown of these four operations. Refer to Annex B for the joint tactical tasks as found in CJCSM 3500.04C, *Universal Joint Task List (UJTL)*. Both lists should serve as a basis for developing scenarios or vignettes for simulation modeling and should be fully represented in order to determine the effectiveness of the soldier systems in all potential operations.

The referenced task lists imply that we need to model our own and allied forces, enemy forces and their allies, and neutral forces. Furthermore, the simulation should represent regular military and guerilla forces, terrorists, and civilians, both armed (including police) and unarmed (to include NGOs).

III. NON-SOLDIER REPRESENTATION

A. Represent the Environment. Representation of the environment is a complex issue. The requirements and discussion below only touch upon the more important aspects of this representation as they relate to the requirements of PEO Soldier.

1. General Environment Types. The following are the general types of the environments in which the future soldier can be expected to operate. This is not necessarily an all-inclusive list, but is representative of the spectrum of environments that the soldier will experience. If the simulation will also be used for special operations forces (SOF), it may have to include detailed models of special environments like the ocean or the atmosphere.

The following are the primary environment types:

- **Urban, or built up, areas**
- **Desert**
- **Jungle**
- **Swamp / Marshland**

- **Forest / Woodland**
- **Plains / Rural**
- **Mountains**
- **Arctic**
- **Littoral**

2. Terrain. The following are terrain characteristics that must be modeled in the simulation. Each of these characteristics may be different based upon the above environment types. Even within a specific environment type, these characteristics may vary.

a) Relief. The simulation should have a realistic mapping of the surface of the earth, at a high enough resolution to effect the movement and line of sight (LOS) of an individual soldier. This category also consists of what is sometimes called "micro-terrain" or the finely-detailed, very high resolution terrain, like rocks, gullies, mounds, and vegetation. As with vegetation discussed below, it is important to model the effects of this type of terrain, especially as it relates to the soldier's ability to seek cover and concealment, as well as its impacts on sensors that may be part of the soldier system under evaluation. However, this need not be represented explicitly, but can be modeled probabilistically as discussed with vegetation below.

b) Vegetation. The vegetation should be represented in a way that will allow the model to account for its effects on round, fragment, and shrapnel trajectories, visibility, sound, and mobility. It is not necessary for the simulation to specifically model a single bush, plant, or tree. Such vegetation could be accounted for probabilistically based upon the type of environment. The simulation must model how vegetation affects the soldier's ability to detect targets, as well as the soldier's vulnerability to detection by other entities.

c) Soil Composition. This characteristic has a great impact on mobility and therefore should be modeled. Soil composition also affects the soldier's ability to dig and to get dirt or sand for sandbags. This characteristic also includes man-made surfaces such as roads and hardstands.

d) Water. For PEO Soldier's needs, it is may not be necessary to model the ocean or large lakes (except for littoral operations – a Marine-oriented application). However, the simulation must model rivers, streams, and swamps.

e) Subterranean Features. This includes man-made and natural tunnels and caves. These features should affect the soldier's ability to move, communicate, and sense.

f) Built-up Areas. The accurate modeling of structures is critical for assessing the effectiveness of any system in an urban environment. The structure models should be able to represent structure interior and exterior, with multiple rooms, multiple floors, construction material properties, windows, doors, "cat holes," and furniture. It should also have attributes that will permit the assessment of weapons effects on the various components of the structure. It should affect the soldier's ability to communicate within the building and between buildings. Additionally, other urban features must be modeled: vehicles, infrastructure (electric and phone cables; poles; gas, sewer, and water lines; etc), paved areas, businesses, gas stations, and general urban layout (roads, alleys, blocks, industrial parks, yards and fences, etc).

g) Other Man-made Features. This includes all types of man-made obstacles, to include minefields (type, dimensions, density), improvised explosive devices (IEDs),

concertina and barbed wire, tank ditches, road and airstrip cratering, 55-gallon drums, and any other man-made feature (except as discussed above in *built-up areas*).

h) Dynamic Terrain. This requirement reflects the ability of the simulation to alter the environment during a run. This type of terrain would account for the effects of the soldier and his weapons upon the terrain, such as blast craters, damage to structures, fire damage, changes to vegetation from deliberate soldier action, etc.

3. Climate. The following are aspects of the climate that must be modeled in the simulation. Each of these characteristics may be different based upon the environment type. Even within a specific environment type, these characteristics may vary both spatially and temporally.

a) Weather Conditions. This includes characteristics such as humidity, barometric pressure, ambient and radiant temperature, visibility, cloud cover, fog, precipitation, ceiling, wind speed, wind direction, inversion factors, and attenuation and extinction coefficients for various portions of the EM spectrum.

b) Light Conditions. This includes characteristics such as sunrise, sunset, BMNT, EENT, angle of the sun, sky-to-ground contrast ratio, moonlight, atmospheric obscurants (e.g., haze) and starlight.

c) Dynamic Climate. This allows for changes to the climate as the day progresses (e.g., temperature, humidity, and barometric changes) and changes due to the soldier and his weapons (e.g., smoke and heat from fires).

d) Man-made Conditions. These conditions include battlefield obscurants, such as smoke and dust; biological and chemical agent contamination and nuclear effects; and illumination and signaling pyrotechnics, such as flares, star clusters, and mortar and artillery illumination rounds. The simulation should represent the different types of smoke and its properties, such as buildup and dissipation characteristics and its effects on different types of sensors. When modeling flares, the simulation should consider dynamic lighting conditions as a result of the wind, trajectory, location with respect to the ground, and burn rate of the flare and how it casts shadows. Additionally, muzzle flashes from all types of weapons, and their effects on observers, should be considered.

4. Other. This includes the effects of insects, wildlife, bacteria, and disease on soldier performance and survivability.

B. Represent Other Entities. This requirements document will not go into the detail for other types of entities as that discussed for the representation of the individual soldier. For this simulation, we are concerned primarily with the representation of the soldier. Therefore, models only need represent other entities to the degree that the soldier will observe or interact with them.

For instance, there may not be need to represent an artillery piece explicitly, only the fires request process, the incoming rounds, and their effects. For a tank, on the other hand, the simulation may be required to model its physical and vulnerability characteristics, its capabilities, and a realistic portrayal of its behavior, depending upon how it will interact with the soldier during the course of the scenario. The same is true of aviation aircraft, personnel carriers, trucks, and other systems the soldier may physically encounter on the battlefield.

C. Represent Higher and Lateral Headquarters. The simulation needs to represent higher headquarters and lateral units (i.e. company and above elements and sister platoons) only to the degree as necessary for communications and directives purposes. For instance, if the platoon leader is attempting to communicate with his company commander on the company net, then the traffic from all company elements on that net should be simulated to ensure a realistic representation of delay. Other representations of higher headquarters might include the ability to attach company mortars or an extra squad, for example.

D. Represent Weapons and Ammunition Effects. While this type of representation is implied in the discussion of the functions below, it deserves special mention. The simulation must represent all types of weapons and ammunition that the soldier may carry or encounter on the battlefield.

For direct fire weapons, the simulation should be able to represent kinetic energy weapons, non-lethal weapons, electromagnetic (EM) energy weapons, and other types of weapons (e.g. flame thrower) delivered via soldier, vehicle, or aircraft-mounted platforms. The model should consider area and point firing, as well as the various firing modes (safe, single shot, burst, fully automatic). It must include direct fire rocket and missile systems. All types of direct fire ammunition should be modeled, to include armor-piercing, HE, sabot, HEAT, saboted light armor penetration (SLAP), canister, anti-structure, etc. The non-lethal direct fire ammunition types that should be represented are the 12 gauge point and crowd control ammunition, 40mm sponge cartridge, 40mm crowd dispersal cartridge, etc.

Similarly, for indirect fire weapons, the simulation should be able to represent lethal and non-lethal weapons delivered via soldier, towed, vehicle, or aircraft-mounted platforms. It should model the fully trajectory of the rounds. Representation of indirect ammunition should include HE rounds (air burst, point detonated, and delay), white phosphorous (WP), illumination, smoke, dual-purpose improved conventional munitions (DPICM), family of scatterable mines (FASCAM), smart munitions, as well as grenades (fragmentary, incendiary, WP, thermite, CS, stun [non-lethal], etc.). The model should account for the entire call for fire process (request, time to fire, time of flight, round adjustment, etc). Also represented in this category should be chemical and biological weapons, their means of delivery, and their effects on the environment and the soldier.

The simulation should also model key firing characteristics (either explicitly or implicitly). Important direct fire parameters include max effective range, rates of fire, bias (variable and fixed), random error, and probabilities of hit, kill, and incapacitation for all possible weapon-munition-target pairings; these must also account for weapon-sensor pairings, such as M4 with CCO or M203 with enhanced laser sights, etc. as these will affect the aforementioned probabilities. Important indirect fire parameters include range, lethal radius, ballistic error, dispersion, aim error, target location error, and probabilities of kill and incapacitation due to fragments and blast effects.

The representation of weapons, ammunition, and explosives must include their effects on targets (humans with various levels and types of protection, structures, vehicles, vegetation, terrain, other objects). Also modeled should be effects based on the part of the target struck

and what level of protection is in that area. Injuries should be affected by treatment, time, and the environment. These effects include not only the effects of hitting the target, but also suppressive effects on personnel nearby (varied suppression duration and level based on the ammunition characteristics, the soldier's protection, and his state of mind).

E. Represent System Reliability and Power Requirements. As in the discussion for weapons and ammunition effects above, system reliability and power requirements are implied by the soldier functions described below. However, it is important to mention briefly here. The advanced technological equipment being fielded for the soldier brings with it power requirements, integration issues, and special maintenance and repair issues. Therefore, it is important, in some way, to model the equipment's reliability and power systems.

The modeling of reliability should account for the failure rates of each of the components and how the various potential component failures would affect the system as a whole. This does not need to be modeled explicitly, but could be associated with probability functions for each potential type of system error and a probabilistic estimation of the repair time for each type of failure. The system failures should affect the soldier's ability to perform certain functions and require the soldier to switch to an alternate method of performing that function, if available.

The power requirements should be modeled based on the mission requirements, power load, and power source capacity, as well as the ability to resupply the power source.

Both reliability and power requirements modeling should consider the effects of the environment on system attributes.

F. Represent Network-Centric Warfare. This is implied in the discussions of many of the soldier functions below; however, it is beneficial to discuss network-centric warfare as one integrated topic, especially its effects on the target engagement process. Clearly, this characteristic of warfare must be represented in any simulation that might be used to evaluate future soldier systems.

The target engagement process can be broken down into five distinct functions, called battlefield information functions (BIF). These are search/detect, identify, track/target, engage, and assess. The responsibility for the performance of these functions is shifting away from the individual soldier to a whole host of systems distributed throughout the battlefield. Thus, sensors may search/detect, identify, and track/target potential enemy targets, engagement logic may trigger an unmanned weapons platform to engage, and sensors may assess the effects of the engagement (Kwinn and Smith, 2001).

As part of this, the soldier may fill any of these roles as either a sensing or engagement platform; however, he may no longer fill all of the roles. Thus, the discussion of soldier functions below, on its own, does not capture the network-centric process. The soldier's role in that process can be captured by his core functions, but the simulation must account for the

digital transfer of information between the soldier and the other network platforms and how that information affects the functions of the soldier and other platforms.

IV. SOLDIER ATTRIBUTES

The soldier entity must be represented by a complete set of attributes that affect the entity's performance of a function (or transformation of inputs to outputs). These attributes can act as inputs or controls. For example, attributes acting as controls may be rule sets for making a decision, a general knowledge base drawn upon by cognitive processes, physical constraints affecting performance, etc. Additionally, these attributes can be affected or changed by the process itself. For instance, movement can reduce the soldier's energy level, operations can increase his experience level, and equipment damage can change its physical and performance characteristics. Many of these attributes are measures of performance (MoPs) for the respective sensor, weapon, or piece of equipment. Attributes can be entered directly or be fed by engineering level simulations. The simulation should consist of a baseline entity, probably the current Soldier, with a standard set of attributes that can serve as a baseline for comparisons.

A. Mission Attributes. These attributes reflect the soldier's knowledge about his mission and how he is expected to accomplish that mission and generally apply to all soldiers in the unit. The ability to model such attributes are critical if this simulation is to be used as part of a DOTMLPF (Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities) analysis, as required by the acquisition process. Such attributes include:

- Doctrine
- Tactics, techniques, and procedures (TTPs)
- Rules of engagement (ROE)
- Standing operating procedures (SOP)
- Soldier's role in the unit / duty position
- Current mission and intent (objectives, control measures, routes, checkpoints, timeline, etc)
- Unit training, experience, and cohesion

B. Personal Attributes. These attributes reflect characteristics of the soldier himself, and may, or may not, vary from soldier to soldier. The attributes must be dynamic and allow for degraded status or changes based on the course of the scenario. Aside from the obvious reasons for inclusion (realism), these attributes can also be adjusted to evaluate various system impacts on performance, relative to soldier size, strength, etc (e.g., a smaller soldier may be incapable of performing certain tasks with a specific combination of system components because it is too bulky, heavy, etc). While the simulation may take such data from engineering level models of human performance, these attributes should still factor into the mission level simulation.

1. Physical Attributes.

- Height, weight, dimensions, shape
- Color, reflectance
- Posture, location

2. Physiological Attributes.

- Fitness, strength, energy, alertness, visual acuity, endurance, fatigue, circadian rhythm
- Sensory motor skills, dexterity
- Health, injury/wound status
- Physical susceptibility to combat (i.e., effects on physiological attributes as time spent in combat increases)

3. Psychological Attributes.
- Courage, initiative, aggressiveness, discipline, self-confidence, fear, trust
- Stress, excitement, motivation (will to fight)
- Obedience (likelihood for following orders, instructions, etc.)
- Effects of casualties (on state of mind, etc.)

4. Mental Attributes
- Memory (short term and long term), cognitive bandwidth, attentional resources
- Reflexive processing, reaction/decision capabilities
- Susceptibility to pressure (either to act or not act, based on actions of other entities, such as peers or superiors)

5. Readiness Attributes. These, when considered with the type of equipment the soldier is using, can be used to determine the impact of the equipment's "user-friendliness" on soldier performance. For instance, a system would be considered user-friendly if a soldier can operate it with minimal training and experience.
- Training
- Experience

C. Equipment Attributes. These attributes reflect characteristics of the equipment, weapons, or clothing worn by the soldier. They may differ by soldier, depending on the type of equipment he is carrying, but are normally constant for a particular piece of equipment. The attributes must allow for degraded status or changes based on the situation. The actual attributes greatly depend on the specific type and model of equipment being represented. Below are some examples by category.

1. Weapons and ammunition attributes
- Maximum effective range, burst/lethal radius, rates of fire, rounds per trigger pull, number of rounds in magazine, fuse time, firing modes (safe, single round, burst, fully automatic)
- Probability of hit (Ph) and probability of a kill or incapacitation given a hit (Pk) for various situations, environments, and postures (for lethal and non-lethal weapons and ammunition)
- Errors
- Suppressive effects
- Reliability, failure rates, failure types, failure modes, durability
- Service (repair) times, maintenance times, ease of diagnosis
- Availability, start up time, standard configuration
- Power requirements, source type, load
- Optical, thermal, electronic and audio signature
- Physical dimensions, weight

2. Sensor attributes

- Cycles per milliradian (CPM) tables, contrast data, spectral band, extinction coefficient
- Range, field of view (narrow and wide), narrow-to-wide factor, image intensification, magnification
- Physical dimensions, weight
- Optical, thermal, electronic and audio signature
- Reliability, availability, repair time
- IFF capability

3. Communications attributes

- Frequency, range, type (analog, digital)
- Security (e.g. frequency-hopping [FH])
- Electronic and audio signatures
- Physical dimensions, weight
- Optical, thermal, electronic and audio signature
- Reliability, availability

4. Clothing attributes

- Optical, thermal, and audio detectability
- Ballistic protection (Ph, Pk based on equipment and clothing)
- EM wave protection
- Chemical protection
- Environmental protection (knee/elbow protection, cold weather gear, wet weather gear)

5. Other equipment attributes

- Capacity, restrictiveness (effects on mobility, dexterity)
- ROM / RAM, processor speed
- Overall system state as a function of individual component failure/incapacitation

V. SOLDIER REPRESENTATION (BY FUNCTION). We decomposed the soldier into two primary functions: decide and act; we continued to decompose those functions to the lowest level we believed necessary for evaluating alternative soldier systems. For the following discussion of requirements by soldier function, we grouped together the decisions and actions that were directly related for ease of understanding and input/output tracking. Therefore, to grasp the actual functional hierarchy, it is best to refer to the hierarchy diagram itself, rather than try to infer the structure from the following discussion.

It is important to note, when looking at the inputs and outputs, the distinction between actual and perceived information. Generally, the soldier makes his decisions based upon his perception of the situation, but his actions are affected by the actual situation. Therefore, the simulation must make this distinction as well, especially since much of the soldier systems being fielded by PEO Soldier enhance the soldier's ability to make decisions by providing more timely and accurate (presumably) information.

A. Assess the Current Situation. This function is a primary driver for most soldier decision making and may be the hardest to model. This assessment is the same as that commonly referred to as METT-TC (Mission, Enemy, Terrain [replaced here by "environment"], Troops

available [replaced here by "friendly situation"], Time available, and Civil considerations). In fact, for the remainder of this document, the acronym METT-TC will refer to this assessment of the current situation. In the case of PEO Soldier requirements, much of the capability enhancements of Land Warrior provide the soldier with information critical to his assessment of the current situation. Therefore, a simulation must model, in some way, how that information affects the soldier's METT-TC assessment, and how that assessment affects his decision-making. Key to this assessment also is the simulation's requirement to track both the information perceived by the soldier, and actual data. Soldiers will make decisions based upon perceived data, but his actions will be affected based upon actual data. Much of the technology being fielded today is designed to improve the soldier's perception, or assessment, of the situation. Therefore, this difference between perceived and actual data must be modeled and tracked in the simulation.

1. Assess the Mission. To meet PEO Soldier's needs, a simulation does not need to explicitly model the soldier's assessment of the mission. However, it must reflect the soldier's knowledge of the mission in terms of the commander's intent, objective(s), control measures, ROE, assigned tasks, etc. Much of this information can be entered beforehand as entity attributes.

- *Modeled Inputs:* None
- *Modeled Outputs:* Perception of mission, to include intent, tasks/purposes, endstates, role relative to other friendly elements (higher, adjacent, subordinate) and vice versa, systems/units in support, commander's intent, objective(s), control measures

2. Assess the Enemy Situation. This is key for Land Warrior. The Helmet-Mounted Display (HMD) and Commander's Digital Assistant (CDA), as well as the increased communication capability, in Land Warrior allow the sharing of knowledge about the enemy situation. The requirement that any soldier system be conversant with Stryker systems (FBCB2) and other digital systems also enhances this soldier function. Therefore, this capability must be represented.

- *Modeled Inputs:* Perceived enemy information from HMD, CDA, communications, other sensing equipment, soldier observation, and soldier training and experience
- *Modeled Outputs:* Perception of enemy composition, disposition, strength, capabilities, weaknesses, doctrine, and tactics

3. Assess the Friendly Situation. For the same reasons as above, this must be represented in simulation.

- *Modeled Inputs:* Friendly information perceived from HMD, CDA, communications, other sensing equipment, soldier observation, and soldier training and experience
- *Modeled Outputs:* Perception of friendly composition, disposition, strength, and capabilities

4. Assess the Environment. Current PEO Soldier programs do not yet directly aim to increase the soldier's capability to assess the environment around him. Indirectly, shared information between soldiers can improve the soldier's information. In order to make the simulation realistic, however, it should represent the soldier's assessment of the environment, which will affect subsequent decisions, especially those related to movement, engagements, and communication. The commonly used acronym for this

soldier assessment is OAKOC (Obstacles, Avenues of approach, Key terrain, Observation and fields of fire, Cover and concealment).

- *Modeled Inputs:* Sensed information, communications
- *Modeled Outputs:* Perception of OAKOC, including terrain, vegetation, weather, slope, soil type, and light conditions

5. Assess the Time Available. Many current PEO Soldier systems aim to reduce the time to make a decision by providing more timely and accurate information (situational awareness). Therefore, the simulation should model the soldier's assessment of time to represent its effects on the soldier's action and decision cycles. Effects on his action cycle might include speeding up a movement rate to meet a hit time when delayed by an incidental enemy contact or moving off the planned route. An example involving the soldier's decision cycle is shortening his engagement decision process based upon an unexpected threat. He may have to fire reflexively or plan a hasty attack based on his assessment of the time available. This is especially important in urban operations in which targets appear at much shorter ranges and in more unexpected locations.

- *Modeled Inputs:* Sensed time, assessment of other METT-TC elements, sensed information
- *Modeled Outputs:* Perception of the time remaining to accomplish tasks

6. Assess the Neutral/Civilian Situation. As with the soldier's assessment of friendly and enemy situation, information about non-combat entities on the battlefield can be shared via the HMD, CDA, or communication equipment. Therefore, this capability must be explicitly modeled, especially given the wide array of missions the present-day soldier must be prepared to accomplish.

- *Modeled Inputs:* Non-combat entity information perceived from HMD, CDA, communications, other sensing equipment, and soldier observation
- *Modeled Outputs:* Perception of non-combat entity disposition (population centers, personnel locations), composition (cultural, religious, ethnic entity mix, sensitivities, traditions), capabilities (armament, equipment), and loyalties.

B. Sense and Making Sensing Decisions

1. Make Search Decisions. A soldier makes decisions to search based upon a tremendous number of factors. PEO Soldier programs directly provide capabilities that affect many of the inputs into search decisions. The capabilities of the sensing equipment that the soldier carries, such as the Thermal Weapon Sights (TWS), Night Vision Devices (NVDs), and Lightweight Video Reconnaissance System (LVRS), will affect these decisions. Additionally, the soldier's assessment of METT-TC, discussed above, will be an input into search decisions. The soldier's searching methods while moving should be consistent with TTPs and not based, for instance, strictly upon direction of movement. When stationary in hasty or deliberate fighting positions, sectors of responsibility will be assigned the soldier based on leader guidance or SOP. The simulation must represent this in some way.

Specific search decisions include:

- **Choose to Search**
- **Choose Search Method**
- **Choose Search Location**
- **Choose Search Timing**

- **Choose to Correct Sensing Equipment Malfunction**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC (especially assessment of enemy threat), knowledge of the soldier's equipment capabilities, sensory cues (primarily audio and visual), battlefield history (previous engagement in a certain area), assigned sector, SOP
- *Modeled Outputs:* Search decisions listed above

2. Search

a) Manipulate Sensing Equipment. A soldier will likely perform certain actions with his equipment before, during, and after searching. These actions take time and draw on the soldier's attentional resources. Usability issues are better studied using prototypes; however, the time required to perform certain actions and the availability of the equipment should be modeled in the simulation. All of the soldier's sensing equipment is not available all of the time. Therefore, to be realistic and to weigh the effects of equipment configuration on unit effectiveness, these characteristics should be modeled to some degree.

Specific sensing equipment manipulation functions include:

- **Change Sensing Equipment Status**
- **Correct Sensing Equipment Malfunction**
- **Emplace Sensing Equipment**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Search decisions listed above, METT-TC assessment, terrain conditions, weather conditions, equipment configuration
- *Modeled Outputs:* Change in equipment status, reduced attentional resources, elapsed time, audio signature

b) Orient. Once the sensing equipment has been readied, if necessary, the soldier must orient himself and/or his equipment in the required direction. This orientation may take time, especially for more complicated types of sensors, and should be modeled. This function includes continuous changes to orientation, as in scanning.

Specific orient functions include:

- **Orient Sensing Equipment**
- **Orient Self**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Search decisions listed above, terrain conditions, weather conditions, equipment characteristics, field of view, scan time and technique
- *Modeled Outputs:* Change in equipment orientation, change in soldier orientation, elapsed time

c) Observe. Many PEO Soldier products are designed to improve the soldier's capability to observe. Most, if not all, of these are designed specifically for improving his ability to see (observe throughout the EM spectrum – visual, image intensification, IR, thermal); however, improvements to the soldier's ability to use his other senses are probably not far into the future, and should therefore be modeled. We must consider both the soldier's natural and technologically-enhanced capabilities. Special sensors (e.g., electronic, magnetic, seismic, radioactivity, chemical) would be included under the soldier sense that the signal he receives from the sensor falls under (e.g., a Geiger counter represents detections with an audio

signal, which would fall under *hear*, and a visual meter, which would fall under *see*). Additionally, for the sake of realism, the simulation should model the soldier's ability to detect other cues, e.g. hearing movement, shifting equipment, or weapon reports, or even observations based on fortuitous glances. Finally, discussion should be made of line of sight (LOS). The simulation must consider not only symmetric LOS, but also asymmetric LOS. For instance, a Soldier behind certain types of vegetation, or behind a wall, can see a large portion of the battlefield through a relatively small hole. Conversely, an observer looking in the direction of that Soldier has a very low probability of seeing him. Another key example occurs inside of a building. A Soldier who backs away from a window can still see outside relatively well; however, he significantly reduces his own probability of being seen. A simulation that assumes that if one entity can see another then the reverse is true, is unacceptable when looking at the fidelity required of a Soldier model.

Specific observe functions include:

- **See**
- **Hear**
- **Feel**
- **Smell**
- **Taste**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Weather, terrain, light, and wind conditions; symmetric and asymmetric line of sight (LOS); battlefield obscurant properties; EM waves, audio waves, vibrations, heat, and odors vicinity the soldier's sensory devices; material properties, device capability, physiological capability, optical contrast, target detectability (e.g., camouflage)
- *Modeled Outputs:* Visual, auditory, olfactory, tactile, and taste sensed information; reduced attentional resources; reduced power (if electronic equipment is being used); recognized need for another observation point; recognized need for more information

3. Make Acquisition Decisions. PEO Soldier products directly provide capabilities that affect many of the inputs into acquisition decisions. Again, the capabilities of the sensing equipment that the soldier carries will affect his decisions, especially the method he chooses to acquire a target, and his ability to assess target threat and characteristics. Additionally, the soldier's assessment of METT-TC will be a critical input into acquisition decisions, especially his choice of target on which to focus, given multiple targets.

Specific acquisition decisions include:

- **Choose Acquisition Method**
- **Choose Detection to Focus On**
- **Assess Threat**
- **Assess Target Characteristics**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Observed visual, auditory, olfactory, tactile, and taste information, assessment of METT-TC
- *Modeled Outputs:* Acquisition decisions listed above

4. Acquire. Many PEO Soldier products are designed to improve the soldier's capability to acquire targets. Laser rangefinders and thermal imagers help the soldier locate targets, and higher resolution sights give soldiers an improved capability to identify and classify targets. Therefore, the simulation should be able to model these capabilities under all potential environmental and mission conditions. In fact, the challenge is not so much representing the soldier with technologically-advanced equipment, it is representing the base case with a greater incidence of target location error, misidentification, and misclassification, leading, in some cases, to fratricide.
Specific acquire functions include:

- **Locate**
- **Recognize**
- **Identify**
- **Classify**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Acquisition decisions, combat ID / IFF devices, environmental conditions (especially weather, light [day/night/transition, ambient levels, artificial], and terrain conditions), actual target characteristics/signature, assessment of target characteristics, target location, target activity
- *Modeled Outputs:* Perceived target location, perceived target identification (friend, neutral, or foe), perceived target threat, reduced attentional resources, reduced equipment power, combined effects of multiple sensors being used

5. Make Tracking/Designation Decisions. Soldier decisions in this area are based primarily on his assessment of METT-TC and the results of his searching for and acquiring of targets, objects, or locations. Because of this, PEO Soldier requires a simulation that models these decisions. Tracking is the soldier function of keeping observation on a target for a period of time. Designating is the function of using a device to mark a target for another observer or weapon system.
Specific tracking/designation decisions include:

- **Choose to Track/Designate Targets**
- **Choose Track/Designate Duration**
- **Choose Targets to Track/Designate**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Assessment of METT-TC; perceptions of target location; target identification and threat; target choice (if choice is a moving target); choice to observe a moving target
- *Modeled Outputs:* Tracking/designation decisions listed above

6. Track/Designate. PEO Soldier products include sensors and designators, like the Multi-Function Laser System and the Lightweight Laser Designator Rangefinder (LLDR), that directly affect the soldier's capability to track and/or designate a target, and should therefore be modeled.

- *Modeled Inputs:* Tracking/designation decisions listed above, environmental conditions (especially terrain, weather, and light conditions), target characteristics, target location, target activity
- *Modeled Outputs:* Target being tracked, designated target, reduced attentional resources, reduced equipment power

C. Engage and Making Engagement Decisions

1. Make Engagement Decisions. These decisions rely heavily upon the weapons and equipment that the soldier is carrying, and upon the unit assets at his disposal, as well as his means of bringing those assets to bear. PEO Soldier products, therefore, greatly impact these decisions. Advanced communications and digital equipment should allow the soldier to call upon networked fires with shorter response times. Advanced weapon capabilities and the soldier's ability to fire with reduced exposure will affect his choice of methods and timing. The simulation, then, should represent these engagement decisions. Specific engagement decisions include:

- **Choose Engagement Method**
- **Choose Target**
- **Assess Engagement Effects**
- **Select Engagement Timing**
- **Decide to Disengage**
- **Decide When to Correct Device Malfunction**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC, perceived target location, perceived target identification (friend, neutral, or foe), perceived target threat, perceived target range, perceived target attributes; perceived proximity of target to structures, other entities, and objects; desired effects on target; visual, auditory, olfactory, tactile, and taste sensed information; weapons available; mission requirements; ROE
- *Modeled Outputs:* Engagement decisions listed above

2. Engage

a) Conduct Close Quarters Combat. Under certain circumstances, the soldier may choose to conduct close quarters combat (CQB), instead of engaging the enemy with a weapon. While PEO Soldier products may not be specifically designed for this purpose, they may affect the performance of these functions. For example, shorter weapons may change the way in which soldiers perform rifle bayonet engagements. Equipment configurations may reduce the soldier's range of motion thereby hindering his ability to fight.

Specific close quarters combat functions include:

- **Fight**
- **Fight with Equipment**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Engagement decisions listed above, actual target location and range, target capabilities, equipment configuration
- *Modeled Outputs:* Effects on target and overall target status, reduced energy level, entity reaction, changed equipment status, physiological effects, psychological effects

b) Employ a Device

(1) Manipulate Engagement Device

(a) Prepare Device. A soldier will perform certain actions with his weapons and equipment before, during, and after engaging. These actions take time and draw on the soldier's attentional resources. As mentioned before, usability issues are better studied using prototypes; however, the time required

to perform certain actions and the availability of the weapons and equipment must be modeled in the simulation. To be realistic and to differentiate between optimal weapons for particular system configurations, these characteristics should be modeled in some way.

Specific manipulate engagement device functions include:

- **Arm Engagement Device**
- **Load Engagement Device**
- **Emplace Engagement Device**
- **Correct Engagement Device Malfunction**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Engagement decisions listed above, METT-TC assessment, device configuration, device status
- *Modeled Outputs:* Change in device status, change in device characteristics, reduced attentional resources, elapsed time, audio signature

(b) Aim Device. Products such as aiming lights, the Integrated Laser White Light Pointer, Multi-Function Laser System, and the Sniper Night Sights directly impact this function and require that the simulation represent the aiming process for the various types of equipment.

- *Modeled Inputs:* Engagement decisions listed above, perceived target location (range and direction), and target exposure (posture)
- *Modeled Outputs:* Change in device orientation, reduced attentional resources, elapsed time, change in equipment status, reduce equipment power, EM wave (in the case of laser and white light sights)

(2) Fire Weapon. All weapons and ammunition developed by PEO Soldier require an accurate representation of this function. This should include all weapons and ammunition discussed in Section III.D.

- *Modeled Inputs:* Engagement decisions listed above, actual target location and range, weather conditions, wind conditions, terrain (including vegetation), weapon status, equipment configuration, device orientation (deflection, elevation), firer posture, target posture, laser designation, attentional resources, probability of hit, probability of kill
- *Modeled Outputs:* EM wave (e.g., a visual signature or a laser or high powered microwave (HPM) weapon), thermal effects, smoke, audio signature, olfactory signature, ballistic trajectory, EM trajectory, terminal effects on target (human, equipment, structure, environment – including collateral damage), suppressive effects, entity reaction, effects on the environment and its reaction, change in weapon status, reduction of available ammunition, elapsed time, physiological effects on firer, accuracy (fixed and variable biases and random errors), round dispersion, adjusted Ph given a sensed missed, adjusted Ph give a miss not sensed, targeting adjustments. These outputs must also generate some battle damage assessment (BDA) for the soldier that provides him with either confirmed or perceived effects of his engagement (feedback loop). The level of confirmation or perception, relative to the desired effect of the

engagement, will serve as inputs into some other decide/act process (e.g., either a re-engagement, search for new targets, or continued movement).

(3) Detonate Explosive. This function covers explosives that are emplaced and then detonated. Although PEO Soldier programs do not directly deal with the use of explosives, the individual soldier on the battlefield may still use them, especially in an urban operations (UO) environment. Therefore, a simulation should represent this capability and the impacts (positive or negative) that any PEO Soldier system has on the soldier's ability to employ them. Additionally, some weapons and ammunition under development in PEO Soldier programs may replace the need for explosives in certain situations. Therefore, the simulation must model the use of explosives as the base case against which to compare advanced PEO Soldier capabilities.

- *Modeled Inputs:* Engagement decisions listed above; explosive properties, preparation, and location; weather conditions, wind conditions, terrain (including vegetation); structural properties
- *Modeled Outputs:* EM wave, thermal effects, smoke, audio signature, olfactory signature, shrapnel and projectiles trajectories, terminal effects on targets, objects, and structures (including collateral damage), suppressive effects, entity reaction, effects on the environment and its reaction, change in explosive status, reduction of available explosives, elapsed time

(4) Throw Device. This function primarily deals with grenades, but applies also to any object that can be thrown to affect a target, including explosives that are designed to detonate on impact, other thrown weapons (e.g., Molotov cocktails), and even rocks. Grenades are important to model in the simulation since they are a PEO Soldier product. Other objects could be critical to model when representing peacekeeping scenarios. Additionally, a soldier tactical mission system (STMS) may impact the soldier's ability to throw the device.

- *Modeled Inputs:* Engagement decisions listed above; chemical and explosive properties; weather conditions, wind conditions, terrain (including vegetation); structural properties; equipment configuration (e.g. restricted range of motion)
- *Modeled Outputs:* These vary tremendously depending on the type of projectile thrown: EM wave, thermal effects, smoke and smoke propagation, audio signature, olfactory signature, shrapnel and projectile trajectories, terminal effects on targets, objects, and structures (including collateral damage), suppressive effects, entity reaction, effects on the environment and its reaction, change in projectile status, reduction of available projectiles, elapsed time

D. Move and Making Movement Decisions

1. Make Navigational Decisions. This is another key capability gap that PEO Soldier products aim to address. Each of the primary navigation decisions are aided by GPS equipment, the HMD, and the CDA. Not only must a simulation that can be used for analysis of alternatives represent the benefits of those types of equipment, but it must also represent comparative cases, e.g., navigation errors caused by use of only a 1:50000 map

and a lensatic compass. Additionally, navigation representation must account for the soldier's reaction to natural and man-made obstacles encountered during movement. On a smaller scale, these decisions encompass soldier movements towards cover and concealment. Special mention should also be made of the simulations requirement to track both perceived and actual data. In a navigational context, the comparison of actual and perceived data and their effects on soldier decisions are critical for assessing the effectiveness of GPS equipment.

Specific navigational decisions include:

- **Determine Location**
- **Choose Destination**
- **Choose Route**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC, with particular focus on assessments of the mission, enemy, and terrain (OAKOC); information from navigational aids (e.g., maps, photos, compasses, digital compass, GPS, feeds from sensory equipment, communicated information and directives); perception of terrain; perceived location (output of one decision, input into another), recognized need for another observation or firing point
- *Modeled Outputs:* Perceived location, perceived distance, perceived time, navigational decisions listed above

2. Making General Movement Decisions. Movement techniques include traveling, traveling overwatch, and bounding overwatch. Movement methods include walking, running, crawling, jumping, etc. The primary drivers for these decisions are the soldier's perception of the enemy situation, the terrain, and the time remaining to complete the mission. Again, the information shared via the CDA, HMD, and communication equipment can aid the soldier in making these movement decisions and should be represented in the simulation. As above, the mistakes made in the absence of these devices should be modeled by the simulation as well. The simulation should also model the choice of movement methods to avoid detection (slower, crouched, deliberate)

General movement decisions include:

- **Choose Movement Technique**
- **Choose Movement Formation**
- **Choose Movement Method**
- **Choose Movement Timing**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC, with particular focus on assessments of the enemy, terrain (OAKOC), and time remaining to complete the mission; information from navigational aids (e.g., maps, photos, compasses, digital compass, GPS, feeds from sensory equipment, communicated information and directives); perception of terrain, perceived location, perceived time and distance
- *Modeled Outputs:* General movement decisions listed above

3. Change Physical Location. The actual physical functions of moving from one location to another are not directly aided by current PEO Soldier programs, with the exception of some climbing aids for urban operations (UO). However, future soldier equipment could include exoskeletons and other muscular aids that would strive to enhance basic human movements, strength, etc. Regardless, the weight of the equipment

carried and worn by the soldier affects these functions. In order to determine the effectiveness of one soldier tactical mission system (STMS) over another, the simulation should model the effects of soldier equipment on his movement rate, degrees of motion on his joints, limitations in his fine motor skills, etc. It is probably not necessary to explicitly model each type of movement in detail; however, the differences in movement rates, levels of exposure, and energy expenditure, as well as the situations and terrain conditions in which these types of movement may be used should be modeled. The simulation must also represent the dynamic changes in soldier attributes during movement (e.g., high crawl, to a rush, to a high crawl, to a combat roll, to moving behind cover, etc).

Specific functions of changing physical location include:

- **Run**
- **Walk**
- **Crawl**
- **Roll**
- **Climb**
- **Swim**
- **Jump**
- **Mount/dismount**

Inputs and outputs of these functions include:

- *Modeled Inputs:* General movement and navigational decisions listed above; actual terrain (including vegetation, soil type, and grade), weather, and light conditions; soldier physiological attributes, especially energy level and physical fitness; equipment attributes (especially weight, bulkiness, and other restricting attributes); use of equipment that can assist in these functions (e.g., life vest, ladder, grappling hook, etc)
- *Modeled Outputs:* Change in soldier location, change in soldier posture, exposure, audio waves, visual cues, physiological effects (especially reduced energy level), change in equipment status, change in equipment configuration, reduced attentional resources

4. Choose Posture. Choice of posture has a great impact on the outcome of an engagement, both in terms of the accuracy of the firer and the exposure of the target to detection and engagement, as well as the exposure of the firer to returned fires. Additionally, the choice to fire from a *reduced exposure* firing position is a key decision provided by Land Warrior. Therefore, the posture decision should be represented in simulation.

Inputs and outputs of this decision include:

- *Modeled Inputs:* Assessment of METT-TC, with particular focus on assessments of the enemy and the terrain (OAKOC), communicated information and directives, SOP, availability of cover and concealment
- *Modeled Outputs:* Choice of posture, choice of posture change timing

5. Change Posture. While the actual transition from one posture to another probably does not need to be modeled explicitly, certain characteristics of each posture and the transitions between those postures should be. For instance, the inability to transition between certain postures due to equipment configuration is important to capture, as is the target area presented to the enemy and the effects on firer accuracy from each position.

Specific change posture functions include:

- **Stand**
- **Crouch**
- **Kneel**
- **Sit**
- **Lie Down (including the prone firing position)**

Inputs and outputs include:

- *Modeled Inputs:* Decision to change posture, choice of posture change timing, equipment configuration
- *Modeled Outputs:* Change in posture, reduced exposure, physiological effects, firing and throwing accuracy (e.g., changes in the probabilities of a kill, hit, etc), sound produced, visual cues, change in equipment state

E. Communicate and Making Communication Decisions. In general, the simulation model must consider communication capabilities above, below, and lateral to the soldier. It must consider issues like integration and interoperability with digital systems (FBCB2, artillery systems), both mounted (especially in the case of Stryker) and dismounted. It should model enhancements in range and non line-of-sight (NLOS) capabilities. In the case of Land Warrior, communications includes not only radios, but the HMD and CDA.

1. Make Transmission Decisions. Communication is critically important to the soldier systems being fielded currently and in the future. In addition to the ability to transmit voice data, soldiers can transmit digital data as well, allowing for a greater exchange of information. Much of the information sent and received by personnel and devices (e.g., information transmitted via satellite or UAV) supports the decisions made by the soldier on the battlefield. Therefore, it is important that these decisions and functions be represented by the simulation. Finally, the simulation should model soldier's choice to transmit based upon the level of combat activity. For instance, soldiers are unlikely to type in data during a firefight or other activity that requires significant attentional resources.

Specific transmission decisions include:

- **Decide When to Transmit**
- **Decide What to Transmit**
- **Decide How to Transmit**
- **Decide Whom to Transmit to**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC; perception of the terrain; perception of the enemy situation; visual, auditory, olfactory, tactile, and taste sensed information; recent engagements; entity attentional resources due to current activity; SOP; communication received
- *Modeled Outputs:* Transmission decisions listed above

2. Transmit. This function includes all types of communication including verbal, hand-signaling, writing, typing information into a CDA, etc. As more devices on the battlefield transmit information, issues like bandwidth availability become important. Therefore, the simulation must represent these transmissions and the effects of information loss due to bandwidth issues. The simulation must include communication with soldier-controlled systems like UAVs, robots, etc. The environment has a

significant effect on transmissions and must also be represented. Also, the time it takes to type data into a transmission device is important to capture when comparing alternative systems. Finally, as discussed above, the simulation should model soldier's ability to transmit based upon the level of combat activity.

Specific transmission functions include:

- **Talk**
- **Type**
- **Write**
- **Signal**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Transmission decisions listed above, entity attentional resources due to current activity, equipment configuration, equipment status, bandwidth load, bandwidth capacity, light conditions, weather conditions, terrain conditions (especially line-of-sight [LOS]), soldier clothing and equipment effects (e.g., effects of MOPP gear), length of the message, background noise and interference
- *Modeled Outputs:* Verbal, typed, written, and signaled communications; change in equipment status; reduced attentional resources; elapsed time; audio signature; visual signature; additional load to bandwidth; reduced equipment power; pyrotechnic effects on the environment; transmission success or failure; accuracy of transmitted information; transmission quality

3. Make Reception Decisions. The decision to receive a communication is not just restricted to the traditional "listening to the radio." It includes other related acts like watching for signals and listening for verbal communication, as well as viewing the HMD, CDA, or GPS to collect information from other sources. As discussed many times previously, PEO Soldier products involve the transfer of this additional information (up, down, and laterally). However, the soldier does not automatically get this information. He must know when and where to seek the information he needs. Therefore, these decisions should be modeled.

Specific reception decisions include:

- **Decide to Receive**
- **Decide How to Receive**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC; perception of the terrain; perception of the enemy situation; visual, auditory, olfactory, tactile, and taste sensed information; recent engagements; SOP; communication received; choice to determine location; choice to locate the enemy
- *Modeled Outputs:* Reception decisions listed above

4. Receive. For the reasons discussed above, receiving communications from other soldiers or information from data devices is critical to the success of PEO Soldier equipped entities. It cannot be assumed that all information available to soldier will be received. Therefore, the distinction between what is received by the soldier and what is not is critical for simulation. Here, we must account for the strengths and limitations of the STMS (e.g. one configuration communicates with FBCB2, the other does not).

- *Modeled Inputs:* Reception decisions listed above, equipment configuration, equipment status, bandwidth load, light conditions, weather conditions, terrain conditions

- *Modeled Outputs:* Change in equipment status; reduced attentional resources; elapsed time; reduced equipment power; visual, auditory, and tactile sensed information; perceived information

5. Manipulate Communications Equipment. A soldier will likely manipulate his communications equipment before, during, and after searching. These actions take time and draw on the soldier's attentional resources. As mentioned with other types of equipment, usability issues are better studied using prototypes; however, the time required to perform certain actions and the availability of the equipment should be modeled in the simulation. To be realistic and to weigh the effects of equipment configuration on unit effectiveness, these characteristics should be modeled in some way. Specific communication equipment manipulation functions include:

- **Change Communications Equipment Status**
- **Correct Communications Equipment Malfunction**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Transmission and reception decisions listed above, METT-TC assessment, terrain conditions, weather conditions, equipment configuration, equipment characteristics
- *Modeled Outputs:* Change in equipment status, reduced attentional resources, elapsed time, audio signature

6. Process Communication Information. Here we are talking about the process of taking the words, signals, sounds, or data received and converting those cues into information that can be used elsewhere. The specifics of how this is done are most likely beyond the scope of explicit modeling since the processes of the human brain are not completely understood. However, what should be captured in some way in the simulation are the effects of information overload on the soldier. Expectant results would include information this is missed, confused, or lost. Here also we should mention the requirement to account for the effects of conflicting or contradictory information (e.g. soldier perception vs. information received from others) as an output of this function that would be an input into other functions and decisions. For example, as information comes in, the soldier processes it and then acts upon it. The subsequent action depends upon the information; if it conflicts with the soldier's current perception, then he may attempt to clarify that information by entering into another (1) *communication* decide-act cycle, or (2) *sense* decide-act cycle.

Specific communications processing functions include:

- **Sort / Prioritize Communication Data**
- **Interpret Communication Data**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Visual, auditory, olfactory, tactile, and taste sensed cues; environmental conditions; physiological and psychological conditions; sorted communications data (output of one function; input into the other)
- *Modeled Outputs:* Information, changes cognitive bandwidth (stimulated or reduced), physiological conditions

F. Enable and Making Enabling Decisions. The enable function serves to capture those functions that a soldier performs that can apply to two or more of the major categories, or functions that the soldier performs to assist in the execution of other functions. Thus, these

actions 'enable' the soldier to engage, move, communicate, and sense, either directly or indirectly, as well as "operate" in the basic human sense.

1. Alter Surroundings and Making Decisions to Alter Surroundings

a) Make Decisions to Alter Terrain. In order to realistically represent a soldier in combat, these decisions should be represented. A soldier in a position for any length of time will begin to prepare a position, whether it is scratching out a hasty fighting position and clearing his fields of fire, or preparing deliberate fighting positions.
Specific decisions to alter terrain include:

- **Decide to Dig**
- **Decide to Build**
- **Decide to Alter Vegetation**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC, perception of the terrain and vegetation, equipment available, SOP, communications from leaders
- *Modeled Outputs:* Decisions listed above

b) Alter Terrain. The actual functions of altering terrain may not have to be modeled explicitly in the simulation. However, given a certain soil type and other terrain characteristics, as well as the equipment available to the soldier, the model should represent changes to the soldier's exposure over time, his ability to sense in his sector (changing LOS), and his energy level.
Specific terrain altering functions include:

- **Dig**
- **Build**
- **Alter Vegetation**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Decisions to alter terrain listed above, equipment available, terrain characteristics (e.g., soil type, vegetation, water table), soldier energy level
- *Modeled Outputs:* Change in soldier exposure, audio signature, reduced energy level, other physiological effects, elapsed time, reduced attentional resources, changes in terrain and vegetation, changes in soldier cover and concealment

c) Make Decisions to Alter Objects. These encompass decisions to clear a path for movement (e.g., move or breach obstacles, open doors), to clear a field of fire (except for altering terrain captured above, such as opening a window or "punching" a hole in a wall), or to alter objects for other reasons. These decisions are especially important in urban operation (UO) environments, in which soldiers must open doors and windows, move furniture out of their way, etc. In other environments, these functions would most importantly involve the soldier's decision to breach or remove obstacles to his movement.
Specific decisions to alter objects include:

- **Decide to Move Objects**
- **Decide to Change Objects**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC, equipment available, perceived environmental characteristics, perception of the terrain, energy level, physiological attributes, SOP
- *Modeled Outputs:* Decisions to alter objects listed above

d) Alter Objects. PEO Soldier programs develop equipment that can perform these functions. For instance, shotguns used to breach locked doors, 40mm rounds that can be used to breach thin walls, etc. In order to capture the effects of these weapons, especially in the UO environment, their capabilities should be modeled.

Specific alter object functions include:

- **Move Objects**
- **Change Objects**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Decisions to alter objects listed above, object attributes, equipment available, ammunition available, energy level, physiological attributes, terrain conditions, weather conditions, light conditions
- *Modeled Outputs:* Change in object attributes, location, orientation, or configuration; elapsed time; reduced energy level; audio signature; physiological effects; reduced attentional resources; soldier exposure as a target; audio signature

2. Manipulate Load and Making Decisions to Manipulate Load

a) Decide to Tailor Load. During the course of a mission, the soldier may make decisions to change his load. For instance, upon making contact, the soldier will probably drop his rucksack until the conclusion of the engagement. When a unit moves into an objective rally point (ORP), they may leave their rucksacks and unnecessary equipment behind, under guard, until the mission is complete. A soldier may choose to pick up an enemy weapon if his ammunition level is low. The soldier may decide to shift equipment around to make some available for use (e.g., pulling equipment from the rucksack or putting unnecessary equipment into it). Therefore, at a minimum, the most basic and common of these decisions should be modeled in a simulation.

Specific decisions to tailor load include:

- **Decide to Add to Load**
- **Decide to Alter Load**
- **Decide to Reduce Load**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC, soldier equipment availability, ammunition level, SOP, energy level, physiological attributes
- *Modeled Outputs:* Decisions to tailor load listed above

b) Tailor Load. The modeling of these functions is important in that they alter the soldier's capabilities based on the change in availability of his equipment. The actual location of the equipment on his body is not critical for modeling; however, his change in capability and availability is. Also modeled should be the ease of tailoring the load.

Specific tailor load functions include:

- **Add to Load**
- **Alter Load**

- **Reduce Load**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Decisions to tailor load listed above, equipment availability, equipment characteristics and configuration, non-soldier equipment available to him, energy level, physiological attributes
- *Modeled Outputs:* Changes to equipment availability, changes to equipment configuration, change in equipment attributes, elapsed time, audio signature, reduced attentional resources

c) Decide to Carry Object. This decision is similar to the decision to tailor the load; however, the intent in this decision is to move an object from one point to another, instead of adding to a load with the intent to use it. The modeling of this decision and the subsequent function is not critical for comparing STMS, but will help make the simulation more realistic for certain situations, especially that of casualty evacuation.

- *Modeled Inputs:* Assessment of METT-TC, soldier load, perceived environmental characteristics, perception of the terrain, energy level, physiological attributes, SOP
- *Modeled Outputs:* Decision to carry an object

d) Carry Object. The function of carrying an object (or person) is critical for realism in some situations, most notably, as mentioned above, casualty evacuation. This function could be an individual soldier or a team of soldiers carrying an object.

- *Modeled Inputs:* Decision to carry an object, soldier load, environmental conditions, energy level, physiological attributes, object attributes
- *Modeled Outputs:* Change in object location, change in load, change in equipment attributes, audio signature, reduced energy level, physiological effects, reduced attentional resources

3. Operate and Making Operation Decisions

a) Decide to Conduct Bodily Functions. These decisions do not necessarily need to modeled explicitly by the simulation, unless the analyst in interested in comparing the advantages of various types of water storage equipment. Their corresponding functions, on the other hand, or rather their effects, should be represented in some way if scenarios are of extended duration.

Specific bodily function decisions include:

- **Monitor Needs**
- **Decide to Consume**
- **Decide to Expel Waste**
- **Decide to Rest**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC, energy level, perceived needs (hunger, thirst, exhaustion, etc), food availability, drink availability, SOP
- *Modeled Outputs:* Bodily function decisions listed above

b) Conduct Bodily Functions. As noted above, the functions themselves do not need to be explicitly modeled; however, the effects of performing, or not performing those functions should be if the scenario is of extended duration. This would ensure that such considerations as the amount and type of food carried, the water carrying capacity, etc, are modeled for evaluation purposes. Also considered should be the ease with which these functions are performed given a specific STMS configuration.

This is important, since it will be the first test it will undergo with soldiers. The last piece may be the role of an engineering level simulation, but the results of that analysis should feed the mission level simulation.
Specific bodily functions include:

- **Consume**
- **Expel Waste**
- **Rest**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Decisions to conduct bodily functions listed above, physiological attributes, water bearing equipment capacity, food characteristics, liquid characteristics
- *Modeled Outputs:* Changes to physiological attributes, reduction in the amount of food and water available, reduced attentional resources (rest)

c) Decide to Administer First Aid. The whole piece of casualty treatment and evacuation must be modeled. To start with, the decisions made by soldiers to treat themselves or others have a tremendous impact on any engagement. Likewise, the decision of a soldier or team of soldiers to evacuate a unit member results in a significant reduction in the available fighting force. Thus, the decision to administer first aid must be modeled to make the simulation more realistic.
Specific decisions to administer first aid include:

- **Monitor Health**
- **Decide to Administer Self Aid**
- **Decide to Administer Buddy Aid**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC, sensed information (either self monitored or sensed from another soldier), communications received, physiological attributes, equipment available, environmental effects on wounds, elapsed time since wounding
- *Modeled Outputs:* Decisions to administer first aid

d) Administer First Aid. The simulation must model the effects of performing first aid, since it is a function performed by soldiers on the battlefield; however, the representation need not be explicit, as long as the probabilistic effects are modeled. Equipment such as clothing with built-in tourniquets or other medically-based uniform construction will need a simulation that can model, in some way, the application of first aid in order to evaluate their effectiveness.
Specific first aid functions include:

- **Administer Self Aid**
- **Administer Buddy Aid**

Inputs and outputs of these functions include:

- *Modeled Inputs:* Decisions to administer first aid, physiological attributes (especially type and location of injury), equipment characteristics, equipment available, skill and training of the soldier
- *Modeled Outputs:* Changes to physiological attributes, reduction in available equipment, reduced attentional resources, reduced energy level, elapsed time

e) Make Equipment Operating Decisions. These decisions encompass the full array of logistical decisions. With each new STMS or piece of equipment issued to

the soldier, the systems become more complex. This dependence upon technology has many important implications for logistical support and maintenance. Therefore, the decisions to perform these functions must be modeled, especially since it is unlikely that a soldier will be able to repair equipment immediately after it fails. Specific equipment operating decisions include:

- **Monitor Equipment**
- **Decide to Maintain**
- **Decide to Sustain / Resupply / Redistribute**
- **Decide to Repair**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Assessment of METT-TC, equipment characteristics, equipment status, repair or maintenance equipment available, level of maintenance/repair required, training of the soldier, SOP, availability of all classes of supplies
- *Modeled Outputs:* Equipment operating decisions listed above

f) Keep Equipment Operating. Included in these soldier functions, are the representations of reliability, failure rates, types of failure, equipment integration issues, durability, equipment damage, power source capacity, and availability of supplies from external sources, repair (service) times, maintenance times, etc. Specific equipment operating functions include:

- **Maintain**
- **Sustain / Resupply / Redistribute**
- **Repair**

Inputs and outputs of these decisions include:

- *Modeled Inputs:* Equipment operating decisions listed above, equipment characteristics, equipment status, repair and maintenance equipment available, training of the soldier, availability of all classes of supplies
- *Modeled Outputs:* Change in equipment status, change in level of supplies, reduced attentional resources, physiological effects, elapsed time, change in equipment characteristics

Annex A. US Army Tactical Mission Tasks and Operations from FM 7-15

ART 8.0: CONDUCT TACTICAL MISSION TASKS AND OPERATIONS
ART 8.1: Conduct Offensive Operations
ART 8.1.1 Conduct a Movement to Contact
ART 8.1.2 Conduct an Attack
ART 8.1.3 Conduct an Exploitation
ART 8.1.4 Conduct a Pursuit
ART 8.1.5 Conduct One of the Five Forms of Maneuver
ART 8.2: Conduct Defensive Operations
ART 8.2.1 Conduct an Area Defense
ART 8.2.2 Conduct a Mobile Defense
ART 8.2.3 Conduct a Retrograde
ART 8.3: Conduct Stability Operations
ART 8.3.1 Conduct Peace Operations
ART 8.3.2 Conduct Foreign Internal Defense Operations
ART 8.3.3 Conduct Security Assistance
ART 8.3.4 Conduct Humanitarian and Civic Assistance
ART 8.3.5 Provide Support to Insurgencies
ART 8.3.6 Support Counterdrug Operations
ART 8.3.7 Combat Terrorism
ART 8.3.8 Perform Noncombatant Evacuation Operations
ART 8.3.9 Conduct Arms Control Operations
ART 8.3.10 Conduct a Show of Force
ART 8.4: Conduct Support Operations
ART 8.4.1 Conduct Domestic Support Operations
ART 8.4.2 Conduct Foreign Humanitarian Assistance
ART 8.4.3 Conduct Forms of Support Operations
ART 8.5: Conduct Tactical Mission Tasks
ART 8.5.1 Attack by Fire an Enemy Force/Position
ART 8.5.2 Block an Enemy Force
ART 8.5.3 Breach Enemy Defensive Positions
ART 8.5.4 Bypass Enemy Obstacles/Forces/Positions
ART 8.5.5 Canalize Enemy Movement
ART 8.5.6 Clear Enemy Forces
ART 8.5.7 Conduct Counterreconnaissance
ART 8.5.8 Contain an Enemy Force
ART 8.5.9 Control an Area
ART 8.5.10 Defeat an Enemy Force
ART 8.5.11 Destroy a Designated Enemy Force/Position
ART 8.5.12 Disengage from a Designated Enemy Force
ART 8.5.13 Disrupt a Designated Enemy Force's Formation/Tempo/Timetable
ART 8.5.14 Conduct an Exfiltration
ART 8.5.15 Fix an Enemy Force
ART 8.5.16 Follow and Assume the Missions of a Friendly Force

ART 8.5.17 Follow and Support the Actions of a Friendly Force
ART 8.5.18 Interdict an Area/Route to Prevent/Disrupt/ Delay its Use by an Enemy Force
ART 8.5.19 Isolate an Enemy Force
ART 8.5.20 Neutralize an Enemy Force
ART 8.5.21 Occupy an Area
ART 8.5.22 Reduce an Encircled/Bypassed Enemy Force
ART 8.5.23 Retain a Terrain Feature
ART 8.5.24 Secure a Unit/Facility/Location
ART 8.5.25 Seize an Area
ART 8.5.26 Support By Fire the Maneuver of Another Friendly Force
ART 8.5.27 Suppress a Force/Weapon System
ART 8.5.28 Turn an Enemy Force
ART 8.5.29 Conduct Combat Search and Rescue
ART 8.5.30 Conduct Consolidation and Reorganization Activities
ART 8.5.31 Reconstitute Tactical Forces

Annex B. Joint Mission Tasks from CJCSM 3500.04C

Note: Many tasks have been deleted from earlier versions of CJCSM 3500.04C.

TA 1 Deploy/Conduct Maneuver
TA 1.1 Deleted
TA 1.1.1 Conduct Tactical Airlift
TA 1.1.2 Conduct Shipboard Deck Helicopter Landing Qualifications
TA 1.1.3 Deleted
TA 1.1.4 Conduct Sea and Air Deployment Operations
TA 1.2 Conduct Passage of Lines
TA 1.2.1 Conduct Air Assault Operations and Air Assault
TA 1.2.2 Conduct Airborne Operations
TA 1.2.3 Conduct Amphibious Assault and Raid Operations
TA 1.2.4 Conduct Counterdrug Operations
TA 1.3 Conduct Countermine Operations
TA 1.4 Conduct Mine Operations
TA 1.5 Deleted
TA 1.5.1 Deleted
TA 1.5.2 Deleted
TA 2 Develop Intelligence
TA 2.1 Deleted
TA 2.2 Deleted
TA 2.3 Deleted
TA 2.4 Disseminate Tactical Warning Information and Attack Assessment
TA 2.5 Deleted
TA 3 Employ Firepower
TA 3.1 Deleted
TA 3.1.1 Deleted
TA 3.2 Deleted
TA 3.2.1 Conduct Fire Support
TA 3.2.2 Conduct Close Air Support
TA 3.2.3 Conduct Interdiction Operations
TA 3.2.4 Conduct Joint Suppression of Enemy Air Defenses (JSEAD)
TA 3.2.5 Deleted
TA 3.2.6 Conduct Attacks Using Nonlethal Means
TA 3.2.7 Conduct Air and Missile Defense Operations
TA 3.2.8 Conduct Air To Air Operations
TA 3.3 Coordinate Battlespace Maneuver and Integrate With Firepower
TA 3.4 Deleted
TA 4 Perform Logistics and Combat Service Support
TA 4.1 Deleted
TA 4.2 Distribute Supplies and Provide Transport Services
TA 4.2.1 Deleted
TA 4.2.2 Deleted
TA 4.2.3 Conduct Air Refueling

TA 4.2.4 Deleted
TA 4.3 Deleted
TA 4.4 Conduct Joint Logistics Over-the-Shore Operations (JLOTS)
TA 4.5 Deleted
TA 4.6 Deleted
TA 5 Exercise Command and Control
TA 5.1 Deleted
TA 5.2 Deleted
TA 5.2.1 Establish, Operate and Maintain Baseline Information Exchange
TA 5.2.2 Deleted
TA 5.3 Deleted
TA 5.4 Deleted
TA 5.5 Deleted
TA 5.5.1 Conduct Force Link-Up
TA 5.6 Employ Tactical Information Operations
TA 6 Protect the Force
TA 6.1 Deleted
TA 6.2 Conduct Joint Personnel Recovery
TA 6.2.1 Deleted
TA 6.3 Conduct Rear Area Security
TA 6.4 Conduct Noncombatant Evacuation
TA 6.4.1 Deleted
TA 6.5 Provide For Combat Identification
TA 6.6 Deleted
TA 6.7 Deleted
TA 7 Operate In a CBRNE Environment
TA 7.1 Conduct Mission Operations in a CBRNE Environment

Appendix D: Engineering Problem Statement

Soldier Tactical Mission System (STMS) Simulation

Requirement
(Effective Need)

Identify and/or develop tactical combat simulation capability for Light Infantry missions at the level of Platoon and below with resolution down to the individual Soldier. The simulation capability must accept, as input, scenarios and Soldier STMS characteristics. It must model the functions of the Soldier in a tactical environment, and provide, as output, the measures of effectiveness (MOEs) used to evaluate STMS. The simulation(s) will provide the analytical capability to support Program Executive Office (PEO) Soldier decision making.

Simulation Model

The Soldier will remain the key to victory on any Joint mission in which he is involved. Soldiers will accomplish their assigned tasks within units operating as part of the combined arms team in both Joint and Coalition task organizations. Missions will span the spectrum of Joint and Army operations. Because of this, the simulation model must capture the full array of these potential scenarios and evaluate the effectiveness of the STMS to Joint and Army missions. No longer can we be Army-centric in our consideration of materiel solutions.

Soldier attributes and capabilities are integral to operational success in all circumstances. The Soldier must be fully capable of accomplishing the mission and surviving to carry out future missions in situations that will be complex, uncertain, high risk, and rapidly changing. Environment types (urban, jungle, desert, plains/rural, forest/woodland, arctic, mountains, littoral), dynamic terrain (relief, vegetation, soil composition, water, subterranean, build-up areas, man-made features), and dynamic climate (weather, light conditions, man-made conditions) will include all possibilities.

The simulation capability then must represent the Soldier in any combination of the above situations and conditions. It must represent the combined arms team with which the Soldier interacts during the conduct of his mission, including higher and lateral headquarters

elements. It must model the weapon systems and ammunition that the Soldier carries, brings to bear, or faces on the battlefield, to include effects on all types of targets and the environment. It must represent system reliability and power requirements. The simulation capability must consider the network-centric characteristics of future warfare.

The simulation(s) must model the functions of the Soldier performed during the conduct of a mission. On a macro level, the Soldier either acts or decides (a word used to describe all mental processes). Soldier act functions include sense, engage, move, communicate, and enable. The enable function includes those functions the Soldier performs to assist in the execution of other functions. Such enabling functions include altering the Soldier's surroundings, manipulating his load, and operating (conducting bodily functions, administering first aid, and keeping equipment operating). Soldier decide functions include assessing the current situation and making sensing, engagement, movement, communication, and enabling decisions.

In addition to the Soldier functions, the simulation(s) must represent Soldier attributes, and how those attributes affect the functions he performs, i.e., how he transforms inputs to outputs. Attribute types include mission (e.g., doctrine, ROE, SOP, and TTPs), personal (e.g., physical, physiological, psychological, and mental), and equipment (e.g., weapons and ammunition, sensor, communications, and clothing).

STMS Characteristics

Given the simulation modeling capability, the simulation(s) must enable quantification and analysis of the effects of differences in mission capability, survivability, and trustworthiness of STMS as a function of variation in its attributes and characteristics.

The mission capability and survivability of the STMS is a function of lethality, mobility, protection, communications, and situational awareness. A cardinal characteristic of the STMS is the degree to which it is trustworthy as manifest by reliability, availability, maintainability, sustainability, and usability.

A more detailed discussion of STMS characteristics can be found later in this appendix.

Simulation Characteristics

The simulation(s) must interface with the user, process inputs, control processes, transform inputs to outputs, process outputs, and maintain, self-test, and manage redundancy.

Interfacing with the user includes being intuitive (Windows®-like, menu-driven) and understandable. It must allow the user to input scenarios and STMS characteristics, as well as alter entity behaviors and TTPs. It must allow for the extraction of stored data at any time during scenario execution and have a playback capability to view the scenario.

Processing inputs includes managing the simulation's internal data conversion (from inputs) processes, interfacing with other simulations, and accepting data inputs from various sources.

Controlling processes includes HLA compliance, flexibility that allows the integration of additional capabilities, non human-in-the-loop (HITL) simulation execution, stochastic repeatability, fidelity control, preprocessing capability, and optimized run-time.

Transforming inputs to outputs includes the simulation model characteristics discussed above.

Processing outputs includes management of the simulation's internal data conversion (to outputs) processes, continuous or event-driven output capability, interface with external simulations, and exportation of data to external sources.

Maintaining, self-testing, and managing redundancy includes the clear identification and presentation of errors, traceability of errors, and data backup capability to avoid catastrophic data loss.

Discussion of STMS Characteristics

Mission Capable and Survivable

Lethality denotes the ability to acquire potential targets, to assess their characteristics, to engage them at ranges from close-in to extended (by direct or indirect fires), and to ensure they are fully suppressed or defeated.

Mobility demands deployability at all levels (strategic, operational, tactical, & individual) and by all means (air, land, & sea). Strategic mobility denotes deployment inter-theater aboard

USAF aircraft and USN ships. Operational mobility requires efficient transportation of STMS within theater by air-transport (fixed or rotary wing), truck, and rail. Tactical mobility demands quick, agile movement from company-level down to the individual Soldier (by air and on the ground). The STMS must be amenable to tactical air assault; airborne operations; movement on personnel carriers, fighting vehicles, trucks; and foot-movement (approach and assault). Soldiers must remain agile (quickly find cover and concealment) and must be able to rapidly tailor their load for the assault.

Protection must defeat: small caliber ballistics, light shrapnel, lasers, chemical munitions, biologic attacks, fratricide (IFF), and weather related operational challenges.

The STMS must communicate intra-squad and between immediate and adjacent units. It must be able to transmit to and receive digitized information within the chain-of-command.

Situational awareness for Soldiers denotes knowledge, at the squad level, of approximate friendly and enemy dispositions, environmental factors, and viable options.

Trustworthy

Reliable: The STMS will function without hardware or software failure for the duration of the mission.

Available: The components of the STMS required for a mission will be ready for use at the time they are needed.

Maintainable: Components of the STMS requiring servicing or repair can be returned to operational status with a specified time.

Sustainable: The STMS when deployed on a mission can be resupplied so as to continue a mission.

Usable: The STMS can be employed by Soldiers after a specified period of training and experience.

Technologically Advanced

In order to meet the requirement for mission capability, the STMS must be interoperable with present and anticipated related tactical systems. In must be competitive with other known and anticipated systems available to adversaries, enabling our Soldiers to meet or exceed threat capabilities.

Cost-Effective

The contribution of STMS to mission accomplishment and survivability must justify life-cycle costs.

Appendix E: Soldier MAWG Questionnaire

NOTE: The Soldier MAWG surveys were given to us courtesy of the Soldier MAWG team at TRAC-WSMR. These are provided here to give an indication of the questions asked and the type of information obtained. However, the results of and answers to these surveys will not be published due to the sensitive nature of the content. Results in the aggregate can be found in the *Soldier MAWG Evaluation Report* (Larimer, et al., 2004).

SURVEY QUESTIONS:

Model Characteristics Questions: These questions provide general information on the model.

1. Has the simulation been Verified, Validated, and Accredited for any U.S. Army, USMC, or other DoD studies?
   If so, who is the model's accrediting agency and what studies have used the simulation?
2. What level of unit resolution can be represented? What is this model's optimal level of resolution?
3. Has the model been certified for any study related to soldier or small unit issues?
4. Who are your past and present users?
5. How lengthy is scenario development?
6. What scenarios has this simulation used?
7. How lengthy is scenario (replication) run time?
   Given operating system/platform and size/scope of scenario?
   Given mode of execution (single replicate, batch run, operator/analyst-in-the-loop)?
   What is the range of synchronization rates/ratios used (1:1, 1000:1...)?
8. What are the federations or other simulations with which this model has participated / partnered?
9. When is your next release? What improvements are planned?
10. Who has proprietary rights to this model?
11. How flexible is this model to user requirements (adjust source code)?
12. What is the source of terrain data? Where and how is it edited? How easy is it to import NIMA products into the model?
13. How easily can equipment and their effects be generated? That is, can equipment that does not currently exist in the model be easily created?
14. How easily can outputs be catered to the user's needs?
15. Is the model constructive (stand-alone) or require man-in-the-loop?
16. Monte-carlo or deterministic?
17. If monte-carlo, how many replications are typically run?
18. Are statistics produced for the output measures (e.g., confidence intervals)?
19. Can a matrix of cases be set up ahead of time and run without intervention (i.e., batch mode)?
20. Is the model event-sequenced or time-sequenced?
21. What language is it written in?
22. On what computer platforms does it run?
23. What operating system?
24. What are the software and hardware requirements for running the model?

Model Evaluation Questionnaire for the Soldier System

The following pages contain a series of statements about key phenomenon necessary to address individual and small unit analysis issues. For each statement, we ask the model proponent to answer the following questions:

1. Do you think we have adequate knowledge of the real world phenomena to represent it in M&S?
2. How does the model represent the phenomena? (algorithms) Do you think the model adequately represent the phenomena? (If you do not directly represent the phenomena, what is your reasoning/justification for implementing a model shortcut?)
3. Who developed the model's representation of the phenomena? (Organization and POC if possible)
4. How would you like to represent the phenomena?
5. Does data exist that supports the model's representation of the phenomena? Where are data gaps? What are the most important gaps? What are the sources of data?

Modeling Situational Awareness/ C4I

Situational Awareness

1. Information known by the soldier in terms of the following factors:
   Knowledge of own location
   Knowledge of friendly unit/personnel locations
   Knowledge of enemy unit/personnel locations (ground truth versus effects of deception operations/propaganda/PSYOPS, achievement of surprise).
   Knowledge of terrain features (obstacles, roads, bodies of water, contours, etc.)
2. Quality of the soldier's knowledge (i.e. timeliness, error, confidence, etc).
3. The cognitive process whereby the soldier transforms information into awareness and understanding (fusion, association, projection, etc.).
4. Soldier decision-making and behavior, and how they are influenced by situational understanding (causal relationships between information and force effectiveness outcomes). Can the soldier make autonomously make decisions based on his SA?
5. Effects of conflicting or contradictory information (e.g., perceived by soldier entity versus reported by others/portrayed in COP/CROP).

Communications

1. Soldier level communication means.
   Voice, radio
   Voice, face-to-face
   Visual, pyrotechnics
   Data, radio (wireless network)
   Visual, hand and arm signals
2. Threat communications.

3. Communication degradation between soldiers/units affected by the following factors:
   Weather (rain, fog, snow, etc.)
   Terrain (mountains, buildings, etc.)
   Soldiers MOPP level (i.e. communication affected by wearing protective mask).
   Radio types
   Jamming (EW)
   Weapons effects
4. Partial message reception or message misunderstanding.
5. The processes by which the soldier gains and disseminates information (e.g. pushing and pulling information to/from the COP or other soldiers).
6. The process by which non-human sensors (UAVs, robots, etc.) provide information to the soldier.

Command and Control
1. OPORD and FRAGO planning and preparation activities.
2. Issuing of orders at all levels (team, squad, platoon, etc).
3. C2 of robots and semi-autonomous robots.
4. Soldier's and unit's ability to recognize the need to commit reserves, alter plans to respond to emerging threats.

Intelligence
1. Information requirements and prioritization (CCIR).
2. Execution of a reconnaissance and surveillance plan in support of tactical operations.
3. Redirecting (dynamically re-tasking) sensors based on suspected threat situation (confirm or deny incomplete information provided by another sensor).

Modeling Lethality

Acquisition: (please consider humans, robots, and UAVs)
1. Changes in the probability of acquisition of enemy targets given the following factors:
   Level of ambient light (i.e. day/night/transition)
   Natural & man-made obscurants (rain, snow, fog, smoke, dust, etc.)
   Terrain (sandy, mountainous, MOUT, etc.)
   Artificial light (indoor engagements)
2. Availability and use of different acquisition systems based on the situation (night vision devices, thermal sights, iron sights, video sight, etc.).
3. Combined effects of multiple sensors being used by a single soldier.
4. Change of acquisition ability based on the soldier's wear of MOPP equipment (i.e. protective mask).

5. Target acquisition adjustment factors based on the acquisition system.
   Different degrees of acquisition (i.e. detect, recognize, classify, identify)
   Size of target (length, height, width)
   Thermal signature of the target
   Optical contrast of the target against the target's background
   Changing optical contrasts
   Acquisition system field of view
   Soldier's ability to scan a sector of fire with limited field of view acquisition system
   Changing target profiles
   Artificial illumination
   Foliage density and type
   Viewer posture
   Direction soldier is facing; likelihood soldier scans/looks to sides and rear versus maintains attention on assigned sector
   Range from soldier entity to sensor system being used to observe the target (if using robotics, UAVs)
   Target activity
6. Soldier entities passing target information to other soldier entities (i.e. can soldier use information provided by another entity to orient his search/sector of fire).
7. Probability of soldier detection according to the following factors:
   Type of personal camouflage worn
   Electronic signature produced by the soldier's equipment
   Thermal signature produced by the soldier and his equipment
8. The sound (audible) signature produced by the soldier and his equipment (unique to the system so that one soldier can be "noisier" than another) (e.g., while digging hasty defensive positions)
   The olfactory signature (smell/odor/vapors) produced by the soldier and his equipment (detection by domestic animals/guard dogs)
   Presence of biologicals (bio-luminesence flagging combat swimmers, craft; animals of all types potentially reacting to entity's presence)
9. Seismic, acoustic, and magnetic sensors.
10. Soldier scanning

Firing Decision and Engagement Process:

1. Acquisitions and responses based on knowledge of the battlefield, not just on seeing an enemy entity. Examples: soldiers firing into an area where they think the enemy is based on such things as muzzle flashes or last know location rather than just at a specific, seen target.
2. Acquire, decide, and engage in close quarters combat.
   With or without employment of robotics (air, surface (urban/aboard large vessels), subsurface/caves) .
   Quick reaction drill.
   Are robots (if used) solely sensor platforms or are they armed (lethal or non-lethal)?
3. Acquire, decide, and engage with non-combatants.
4. ROE and its effect on the acquire, decide, and engage process.

5. Soldier selection of engagement type given the target and weapons and other assets available (e.g. soldier decision to engage with direct fire, indirect fire, or precision munitions).
6. Target evaluation and selection (i.e. if soldier acquires three targets at the same time, he has to engage one before the other two).
7. Pre-planned fires (direct and indirect) in support of friendly movement.
8. Sector of fire discipline.
9. Soldier's engagement procedure as input to networked fires.

Weapon Effects:

1. Direct fire weapon system effects based on the following factors:
    - Probability of a hit given engagement
        - SSPH
        - PH, given a sensed miss
        - PH, given miss not sensed
    - Probability of a kill given a hit
    - Probability of incapacitation given a hit
    - Range of weapon
    - Rate of fire
2. Indirect fire weapons system factors:
    - Range of the weapon
    - Lethal radius
    - Ballistic error
    - Aim error
    - Target location error
    - Probability of a kill given a hit
    - Probability of incapacitation given a hit
    - Probability of incapacitation given blast effects (hearing loss, organ failure)
    - Ability of selected soldier entities to adjust fire and reduce target location error
    - Suppression effects of indirect fire systems
3. Non-lethal weapons and their effects.
4. Different mechanisms for direct fire effects and how terrain influences them.
    - Fragmentation
    - Heat and flame
    - Pressure
    - Laser
    - Bursting munitions
5. Non-lethal wounds and timeliness of medical care. Environmental affects on wounds.
6. Chemical weapons and their effects.
7. Playing of non-traditional weapon/target pairings (e.g. RPG versus personnel or Hellfire missile into a room).
8. Target designators and their effects on PH.
    - Tracer rounds
    - Laser pointers
    - Precision guided munitions and characteristics of lasing platform
9. Reduced exposure firing and its effect on acquisition and PH.

10. Secondary effects of weapons and collateral damage.
    External and internal damage to buildings
    APS
    Weapon backblasts
    Maingun round spalling
    Structural damage (both internal and external)
    Incidental weapons effects on dismounts (e.g. debris flying off of a building)
11. Laser range finders.
12. Battle Damage Assessment (i.e. how does the shooter know the effects of his rounds?).
13. Flyby effects (i.e. If a round misses its target, is there an effect on other entities/structures located near the target?)?).
14. Weapons being destroyed or damaged by weapons effects.
15. How PH is affected by firer's posture.
16. Ability to pick up / transfer discarded equipment.
17. The following weapon/sensor pairings:
    CCO with M4 (day and night)
    M203 day/night sight
    M4 with TWS (day and night)
    Threat with iron sights at night
    Hand grenade against all targets

Suppression

1. The events that cause a soldier or unit to be suppressed.
2. The soldier's response (behavior) to being suppressed.

Modeling Mobility

1. Soldier's mobility and how they are affected by the following factors:
    Weight of the soldier's load (tires quicker, moves slower with heavier load)
    Restrictive equipment (bulk – limited range of motion for fine motor skills)
    Environment (up-hill movement vs. down-hill, soil type)
    Weather (icy, foggy, rainy, etc.)
    Day/night differences
    Altitude
    Temperature
    Obstacles
2. Soldier fatigue and its effects on movement and task performance.
    For long duration exertions
    For short duration exertions
3. Individual movement techniques.
    Soldier's ability to recognize danger areas and unit's employment of proper danger area crossing techniques to minimize exposure to observation/fires (including posting of security) and use of rally points.
    Soldier's and units ability to recognize the need for and employ alternate routes (e.g., by-pass obstacles, danger areas, identify best covered and concealed approaches)
    Soldier's and unit's ability to recognize need to move to alternate positions.

4. Water crossings / beach landings. Do they account for:
   Water depth
   Current
   Water temperature
   Embankment / beach characteristics
5. Robot mobility.
6. Special movements.
   Climbing / descending a ladder
   Climbing / descending a rope
   Crawling through a tunnel
   Mounting / dismounting a vehicle, aircraft or other platform
   Soldier carrying another soldier
   Skiing, ski-joring, snow-shoeing (including while pulling ahkios)
   Combat swimming (surface and subsurface)
   Paddling rubber inflatable boats (CRRCs)
   Parachuting (free-fall, static-line; steerable or not), including use of weapon/equipment containers and door bundles
7. Dynamic soldier's loads.
8. Non-enhanced land navigation (getting lost/miss-oriented/causing breaks in contact).
9. GPS usage in support of land navigation and jamming of GPS.
10. Unit formations

Modeling Individual Soldier Survivability (Protection)

1. The probability a soldier is killed/injured given he is hit varies with respect to the following factors:
   The type of round that strikes the soldier
   The location of the round striking the soldier (head, torso, etc.)
   The type & body coverage of body armor the soldier is wearing
   The angle at which the round strikes the body armor or helmet
   The distance from the weapon to the target soldier (i.e. accounts for the loss in bullet velocity over distance)
   The likelihood the round first passed through foliage/plaster/doors/windows/water (causing projectile tumble, deflection, velocity reduction, etc).
2. Assessment of appropriate types of injuries, incapacitation, or death based on the factors in phenomenon #1 above.
3. Fratricide.
4. Fratricide prevention systems (IFF).
5. Change of MOPP status during the operation.
6. Casualty assessment on individuals riding inside of destroyed vehicles (for both crew and mounted passengers).
7. Casualty treatment and evacuation. (including disposition/redistribution of critical items)
8. Body armor. Surviving impact but still being incapacitated or degraded.

Human Factors (for both red and blue forces)

1. Training (level of performance based on skill achieved by training prior to model execution – model input).
2. Learning (changes in behavior based on events that occur during the course of a model run or simulated operation).
3. Motivation (will to fight).
   Soldier obedience (independent action, initiative, response to leader orders when other soldier entities elect to follow orders or run, hide, surrender, disobey orders [e.g., willingness to accept decisive engagement versus withdraw before being decisively engaged])
   Soldier acceptance of pressure to act or not act, based upon perceptions/actions of fellow soldier entities.
4. Experience.
5. Unit cohesion.
6. Fatigue.
   Do you represent energy level use (fatigue) or build-up (nutrition intake)?
   Do you model hydration levels?
   Do you represent the effects of these levels on activity/task performance?
7. Effects of casualties on the surviving unit members.

Soldier Equipment Trustworthiness

Modeling Maintainability:
1. Repair/replacement of damaged equipment.
2. Different repair/replacement times for different soldier equipment components .

Modeling Sustainability
1. Logistical concerns:
   Battery failure over time
   Logistical re-supply operations (explicit portrayal by specific classes of supply (e.g., munitions—Class V); impacts on continuity/potential compromise of small unit/special operations)
   Effects of the environment on re-supply requirements (batteries fail sooner in cold weather, etc.)

Modeling Reliability:
1. Failures of different components of the soldier's personal equipment such as weapons, protective gear, acquisition components, etc.
2. Mean Time to Failure (MTTF) used to generate component failures.
3. Reduced capability given an equipment failure (i.e. Thermal sight fails, can the soldier use iron sights until the thermal sight is repaired/replaced)

Modeling the Physical Environment

1. The following types of terrain and the availability/effects of cover and concealment and movement at the individual soldier level:
   - Urban (MOUT)
   - Jungle
   - Mountain
   - Desert
   - Plains
   - Woodland
2. Environmental characteristics and their effects:
   - Temperature (extreme cold/hot)
   - Winds (and the wind's effect on obscurants/chemical & biological agents)
   - Diurnal effects (changing shadows)
   - Precipitation (rain, snow, hail, sleet)
3. Battlefield obscurants:
   - Smoke (generated and natural)
   - Dust as a result of battlefield conditions
   - Atmospheric (fog, haze, light conditions)
4. Changes to the environment (dynamic terrain):
   - Rubble
   - Blowing open a door
   - Breaching a wall
5. Battlefield obstacles and their effects on terrain:
   - Minefields (anti-personnel and anti-tank)
   - Wire obstacles
   - Tank ditches
   - Abatis
   - Road crater
   - Bodies of water (rivers, streams, lakes, etc.)
6. Terrain resolution. What are the effects of higher terrain resolution on model operations?
7. Subterranean avenues of movement.
8. Shielding (cover and concealment) and its effects on acquisition and PK.

Modeling the Mission Environment

1. Other combat systems:
   - Fixed wing aircraft and munitions (Air Force/Navy/USMC attack and bomber aircraft)
   - Rotary wing aircraft
   - Tracked vehicles
   - Wheeled vehicles
   - Watercraft
   - Robots

2. Other weapon systems and their effects on the individual soldier:
   - Direct fire missile systems
   - Indirect fire systems
   - Laser weapons
   - Nuclear weapons
   - Biological weapons
   - Fixed wing delivered munitions (both conventional and precision)
   - Anti-personnel mines
   - Anti-tank mines
   - Thermobaric
3. Non-combatants and the enemies' tactical use of them.
4. Potential combatants.
5. Multiple sides.
6. Cultural environment and civilian affairs (CA) operations.
7. Accommodating and non-accommodating behavior of non-combatants.
8. The contemporary operating environment.
9. Joint sensors.
10. Non-standard threat weapons (booby traps, car bombs).
11. Enemy Prisoners of War.
12. Psychological Operations (PSYOPS - friendly and enemy).

Appendix F: Value Scales

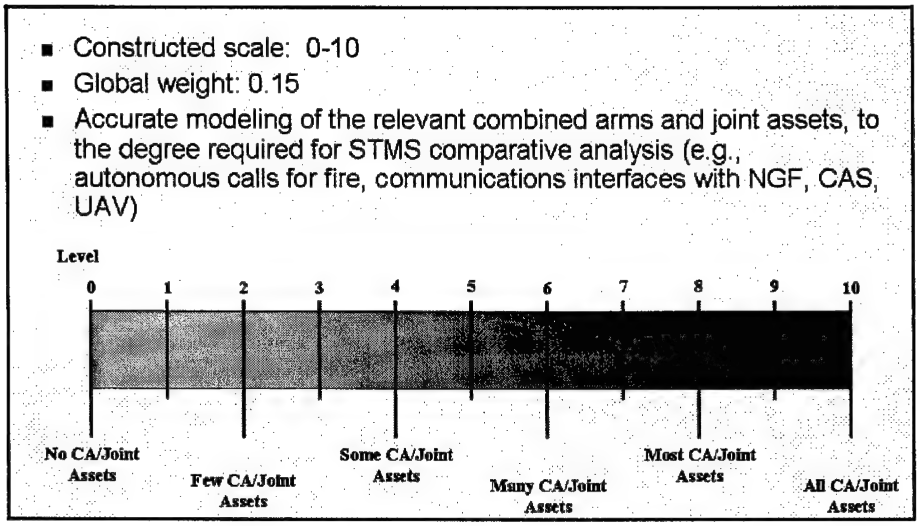

Figure 29. CA/Joint modeling capability value scale.

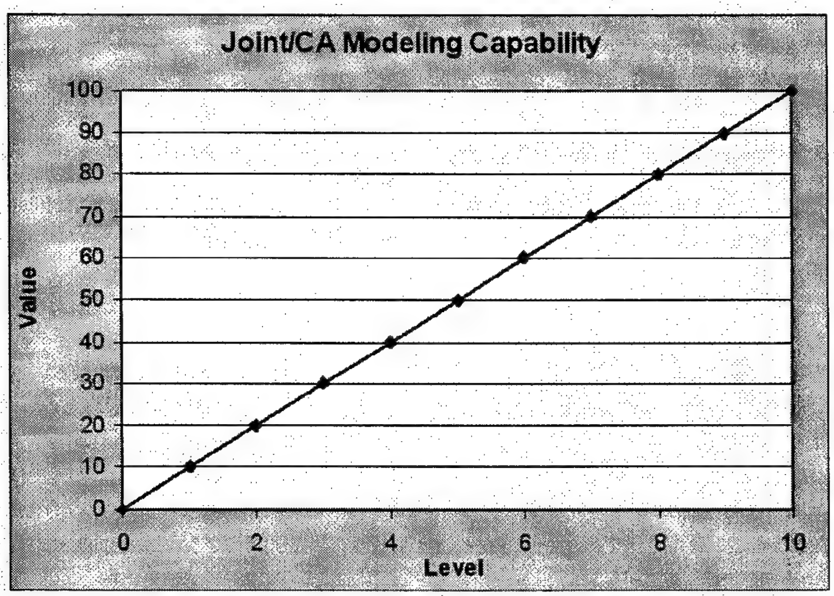

Figure 30. CA/Joint modeling capability value curve.

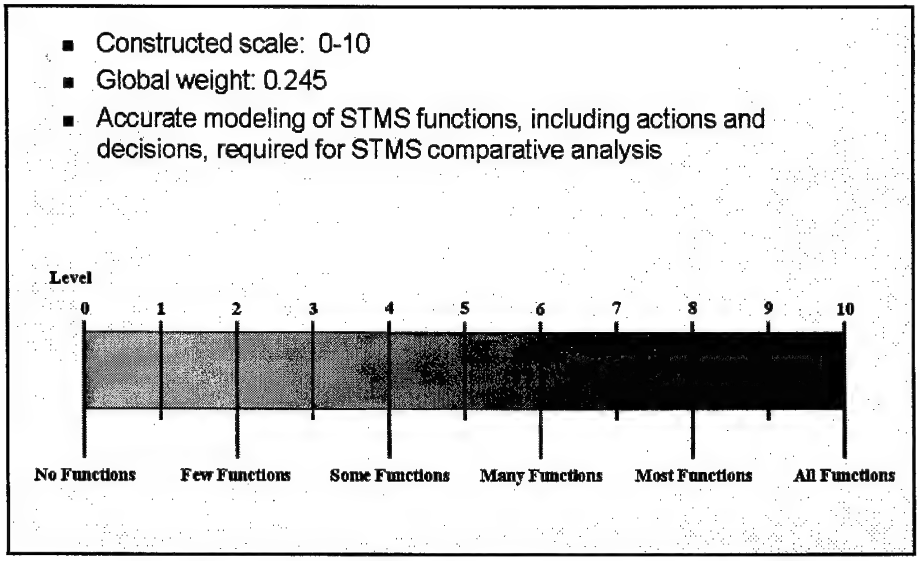

Figure 31. STMS modeling capability value scale.

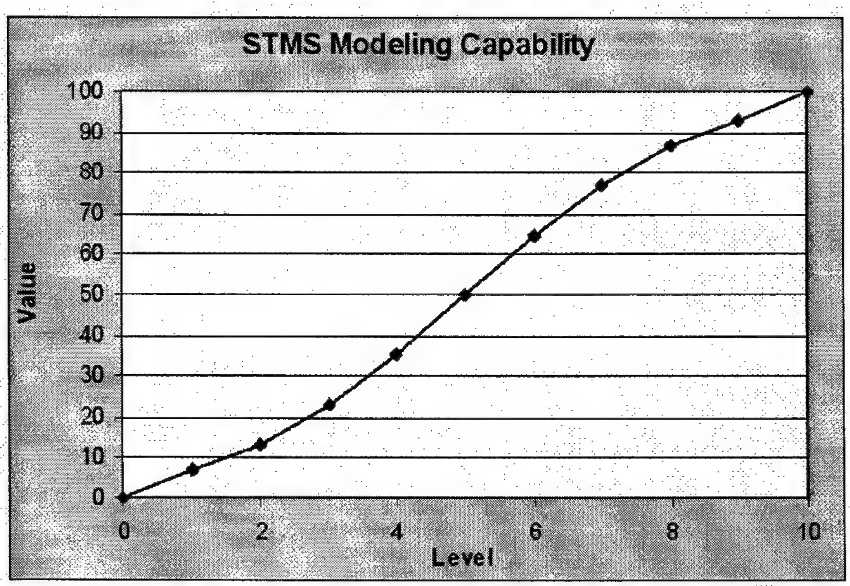

Figure 32. STMS modeling capability value curve.

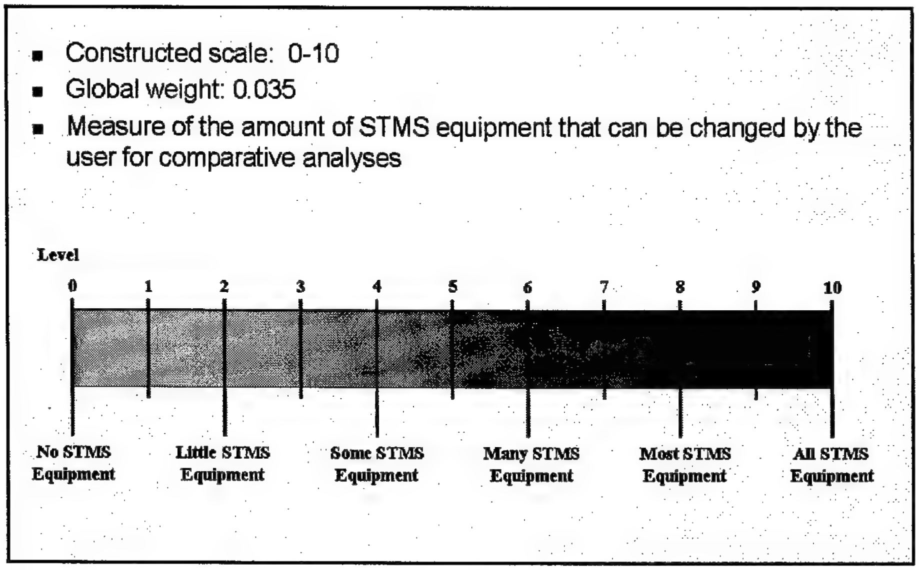

Figure 33. Modifiable equipment types value scale.

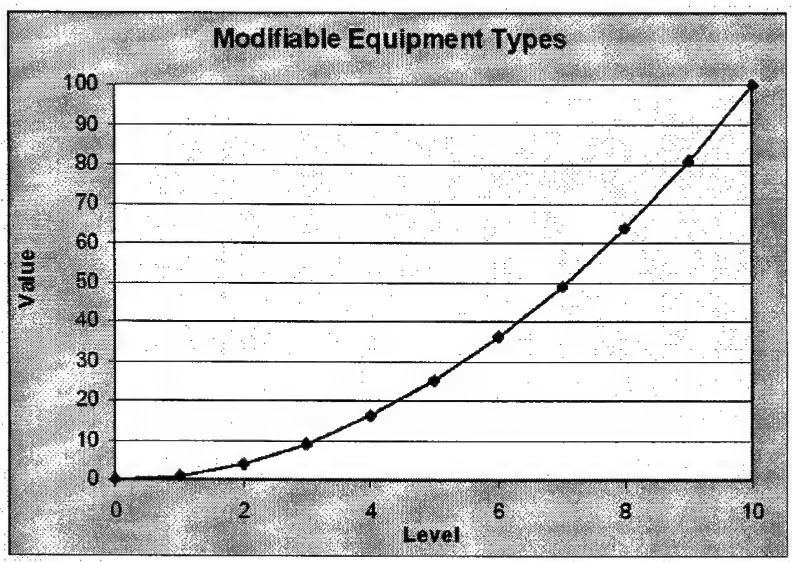

Figure 34. Modifiable equipment types value curve.

- Constructed scale: 0-10
- Global weight: 0.035
- Measure of the amount of control the user has over conditions to the degree required for comparative analysis, specifically dynamic weather and terrain conditions

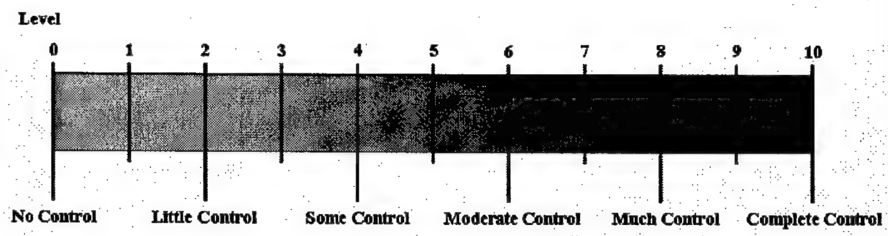

Figure 35. User control over conditions value scale.

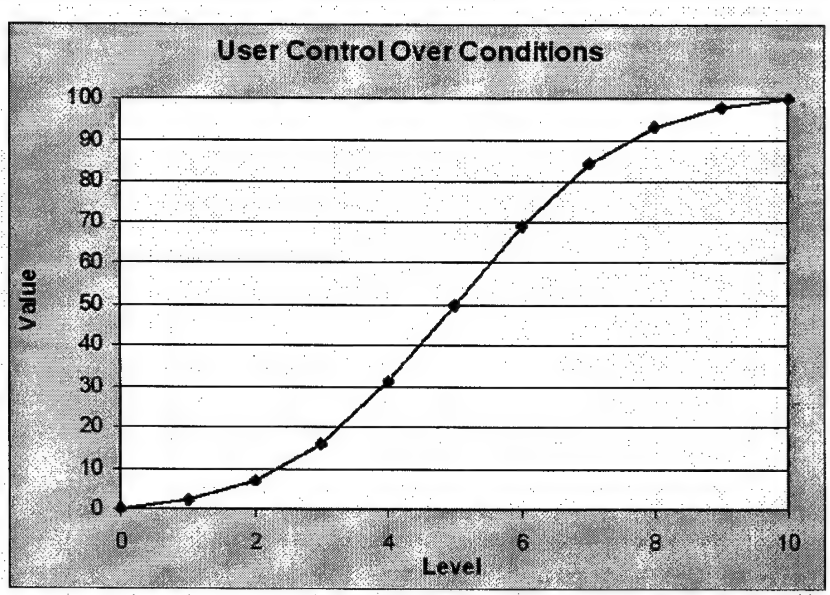

Figure 36. User control over conditions value curve.

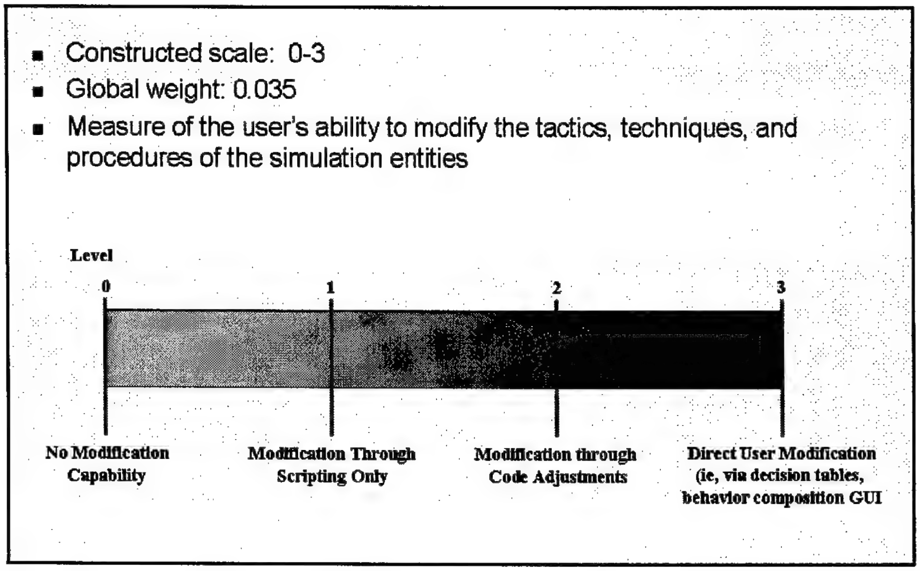

Figure 37. TTP modifiability value scale.

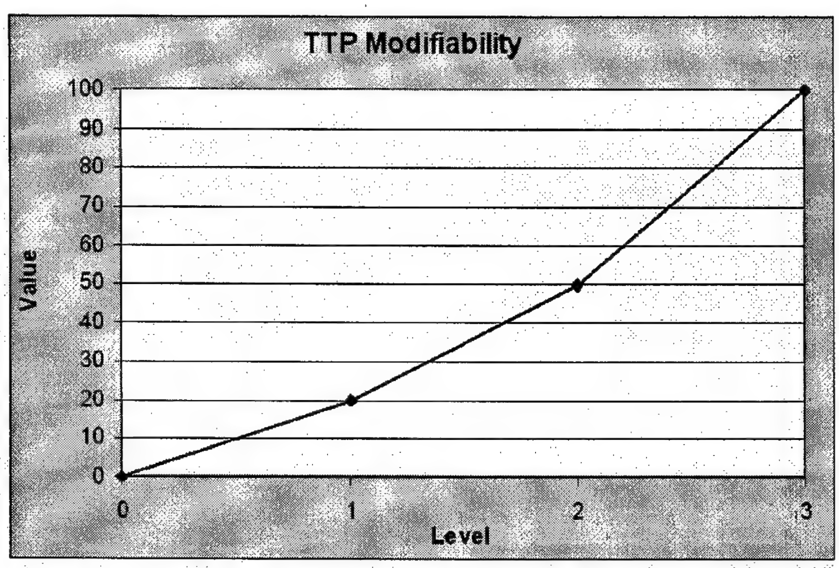

Figure 38. TTP modifiability value curve.

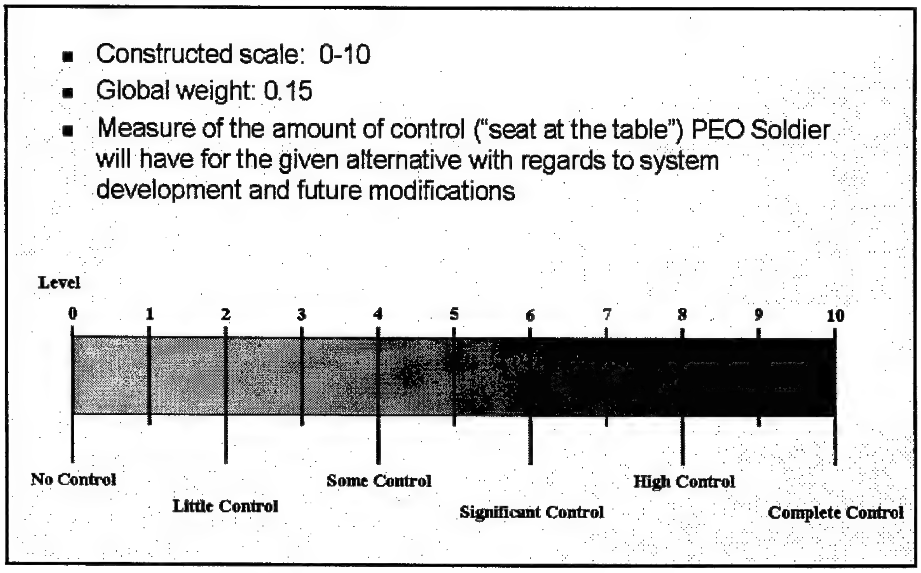

Figure 39. PEO Soldier control value scale.

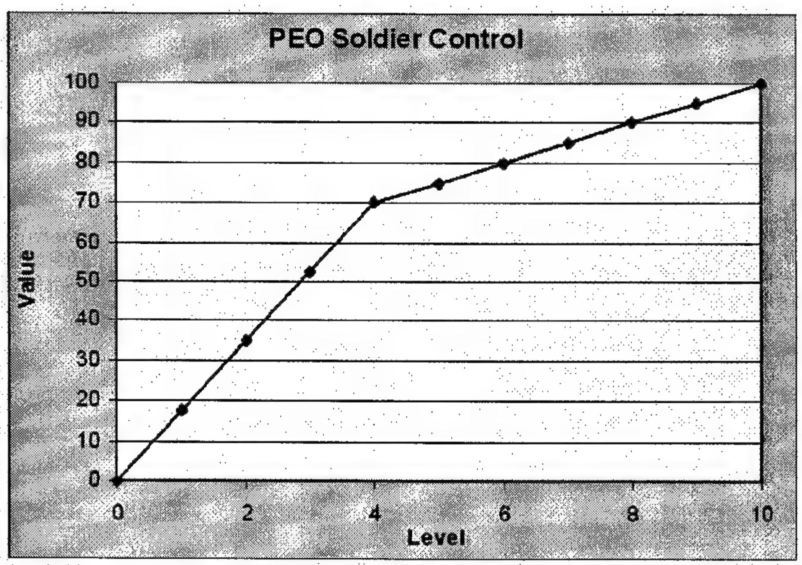

Figure 40. PEO Soldier control value curve.

- Constructed scale: 0-5
- Global weight: 0.15
- A measure of the risk that the simulation development will not be completed (e.g., due to budget cuts, project failure, policy and regulation changes)

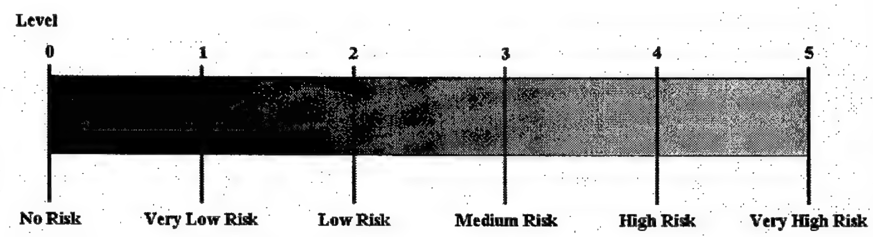

Figure 41. Fielding risk value scale.

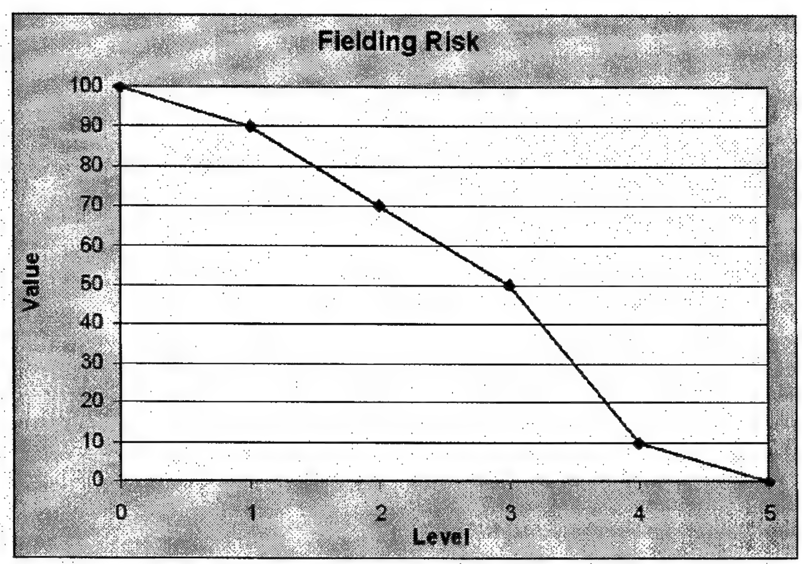

Figure 42. Fielding risk value curve.

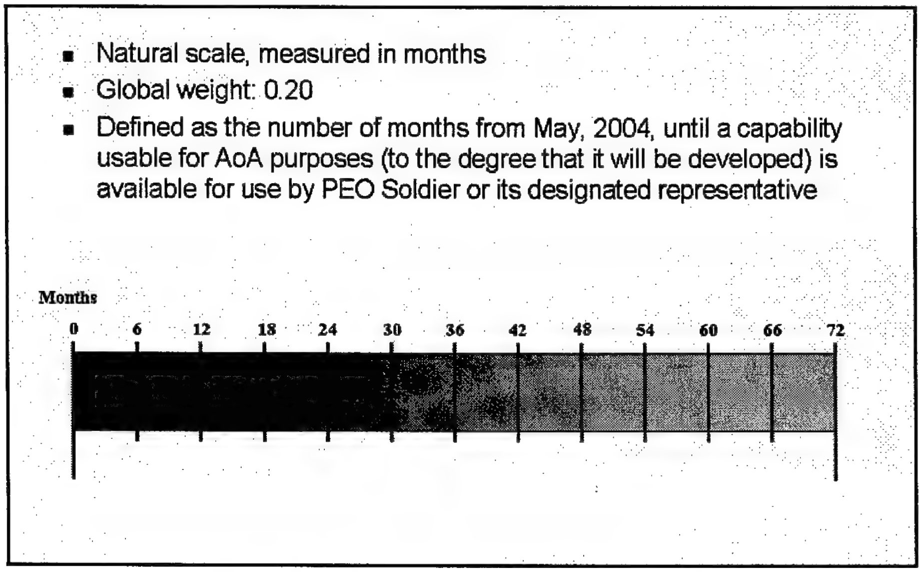

Figure 43. Time until available value scale.

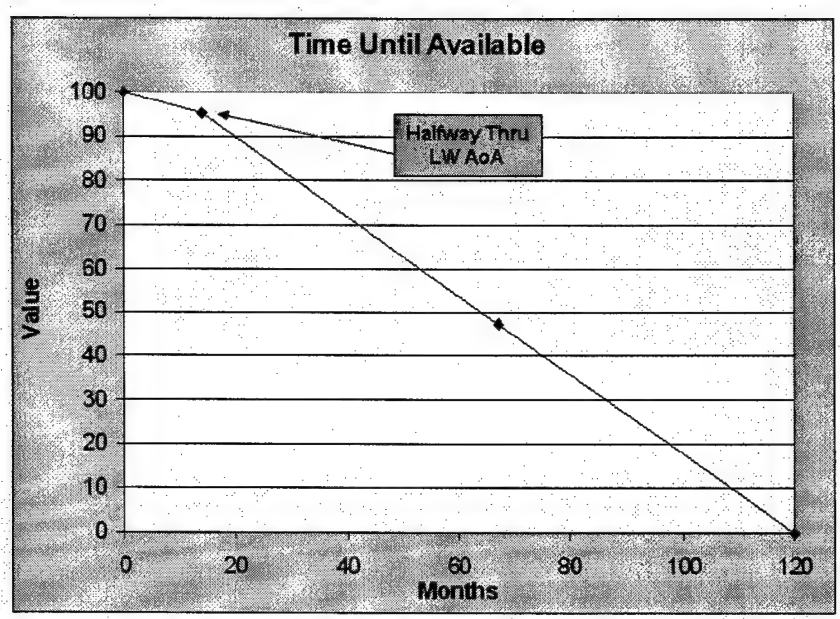

Figure 44. Time until available value curve.

Appendix G: Sensitivity Graphs

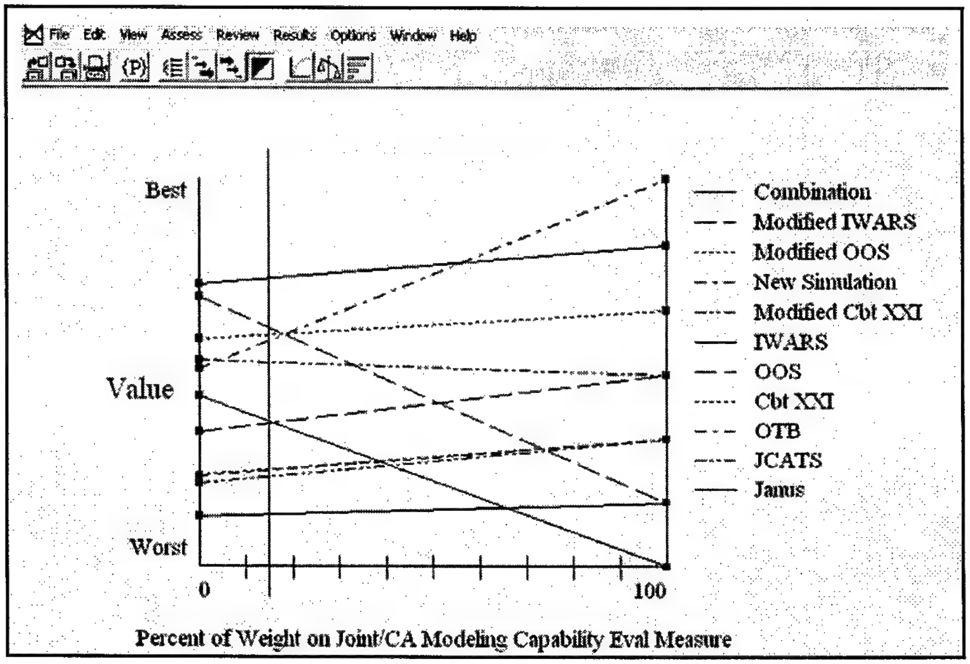

Figure 45. Graph of the sensitivity of the global weight of Joint/CA modeling capability.

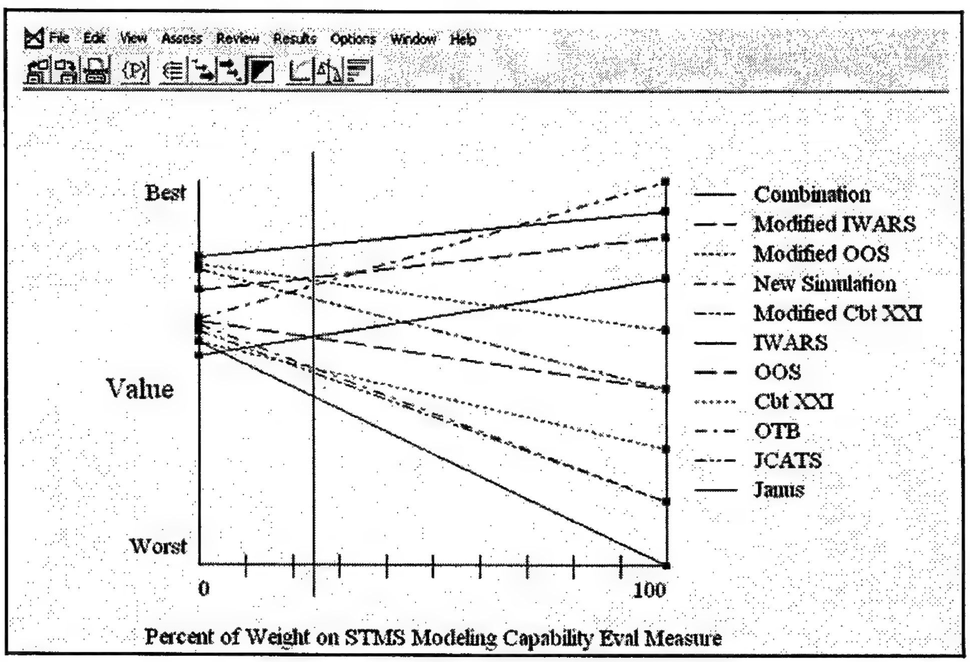

Figure 46. Graph of the sensitivity of the global weight of STMS modeling capability.

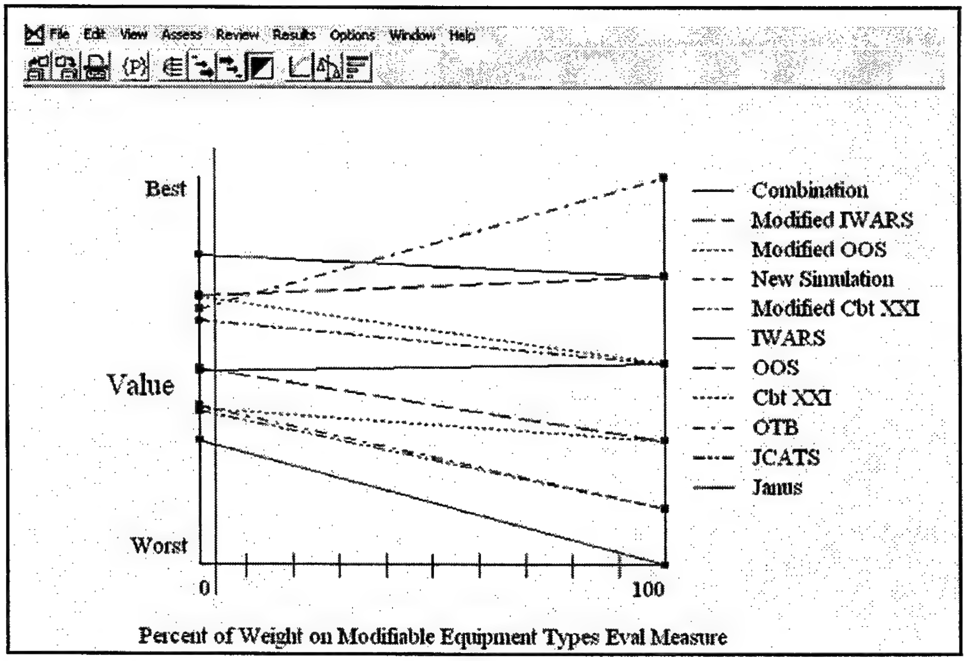

Figure 47. Graph of the sensitivity of the global weight of modifiable equipment types.

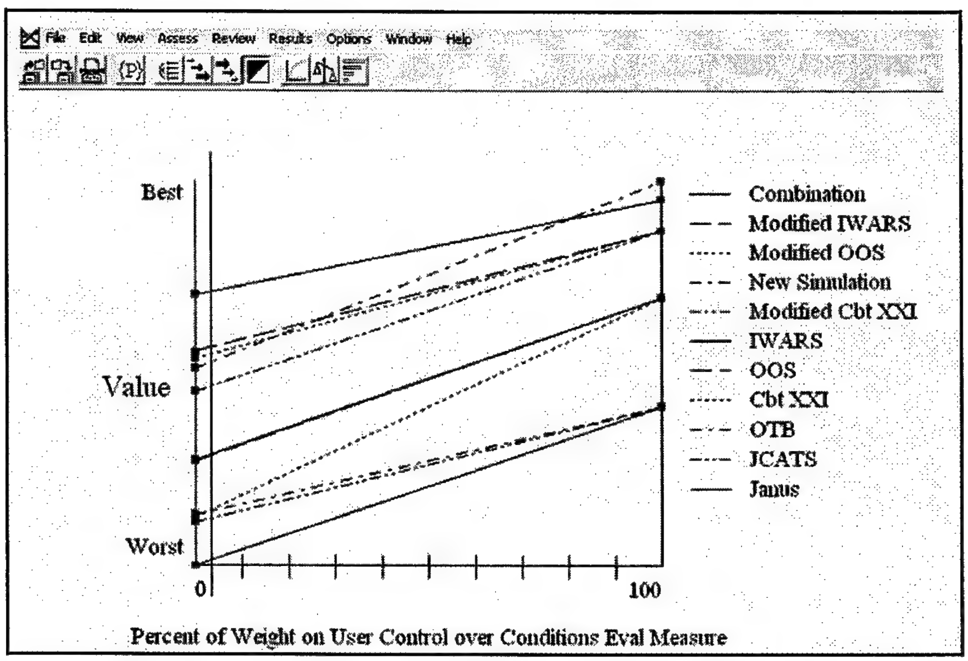

Figure 48. Graph of the sensitivity of the global weight of user control over conditions.

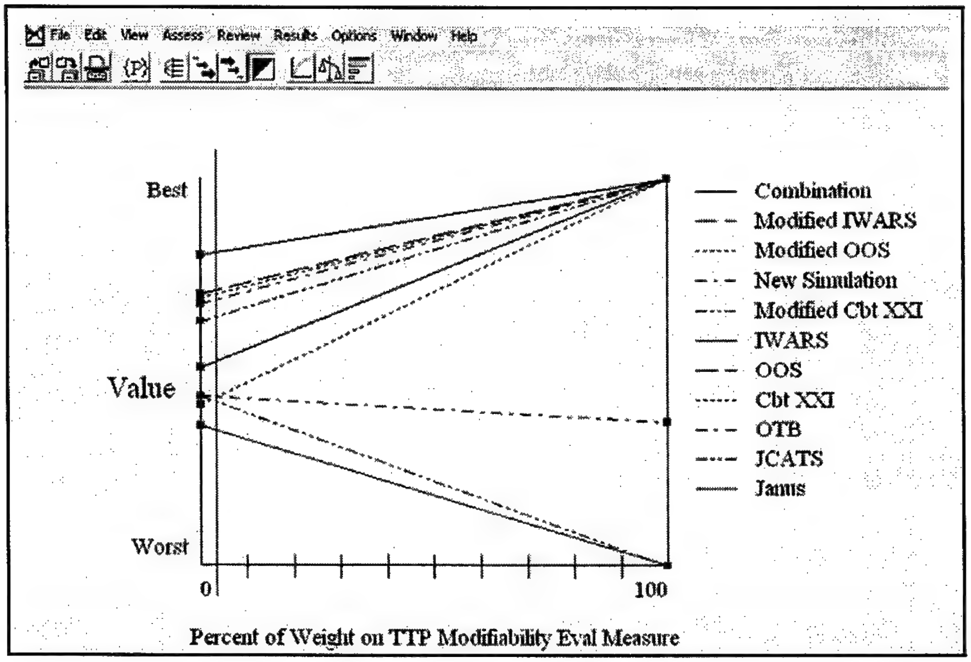

Figure 49. Graph of the sensitivity of the global weight of TTP modifiability.

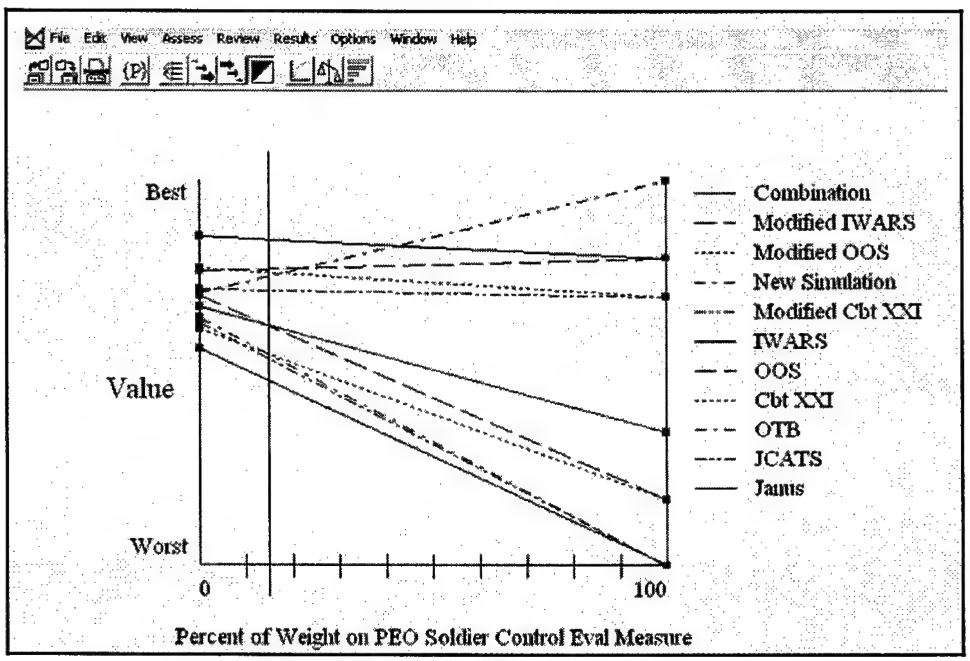

Figure 50. Graph of the sensitivity of the global weight of PEO Soldier control.

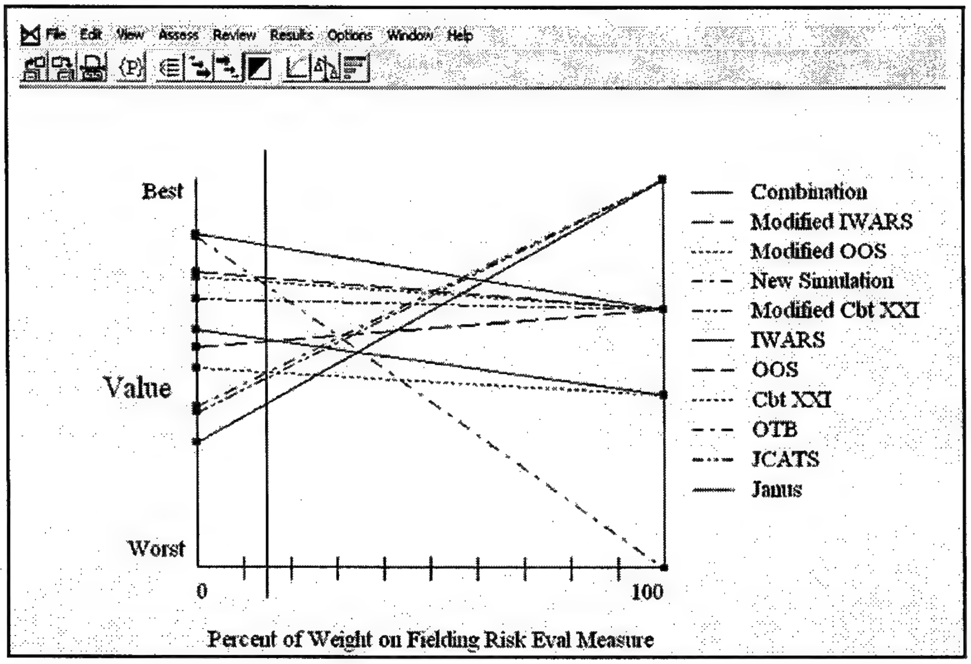

Figure 51. Graph of the sensitivity of the global weight of fielding risk.

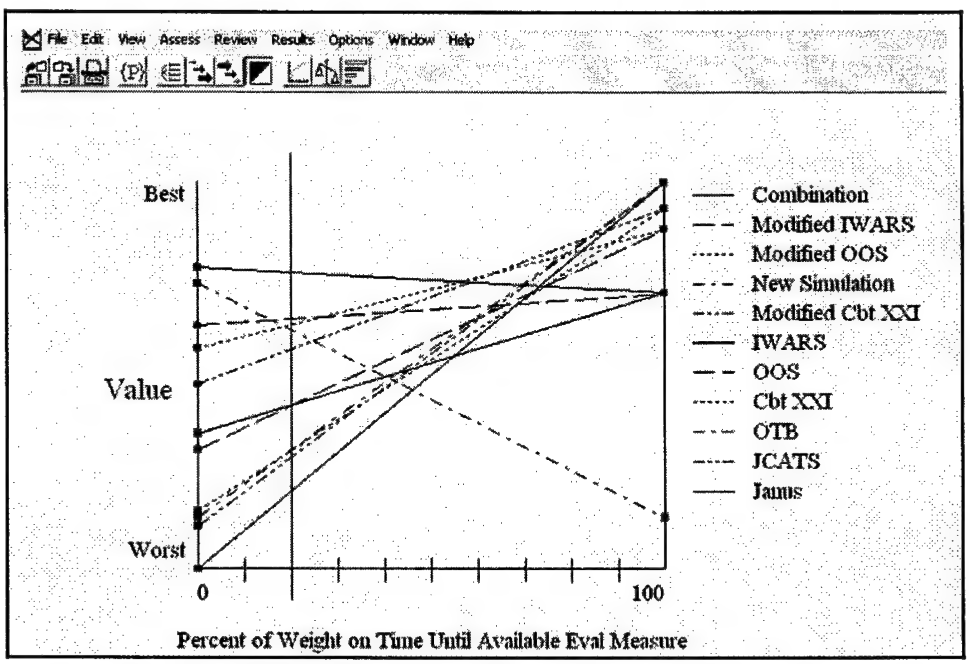

Figure 52. Graph of the sensitivity of the global weight of time until available.

Appendix H: Cost Estimation

The costs listed in the following table are very rough estimates based upon limited information, as several of the models are currently under development. Therefore, these numbers were used only for comparative purposes, not for planning. For most alternatives, we believe that our estimates are on the high side. Our reasoning is described below the table.

Column # →	1	2	3	4	5	6	7	8	9	10	11
Simulation →	Janus	JCATS	OTB	Cbt XXI	IWARS	OOS	Mod Cbt XXI	Mod IWARS	Mod OOS	Combine	New Sim
Modification	$0	$0	$0	$0	$0	$0	$2	$3.5	$3.5	$4.5	$0
Full Development	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$15
Annual Maintenance	$0	$0	$0	$0	$0	$0	$0.5	$.33	$0.5	$1	$1
Total (assume 10 yr horizon)	$0	$0	$0	$0	$0	$0	$7	$6.8	$8.5	$14.5	$25
Total Value Score	48.2	54.0	55.1	55.1	62.6	62.5	71.9	77.1	76.3	84.9	75.3

Table 6. Cost estimation for cost-benefit analysis.

Costs were broken down into three components: 1) the cost required to modify the simulation, 2) the cost to develop a simulation from scratch, and 3) the annual maintenance cost. The total cost was calculated by adding the modification and development costs to 10 times the annual maintenance cost (based on a ten-year planning horizon).

For Existing Alternatives (Columns 1-6): The assumption is that PEO Soldier would not have to provide funding. This may not necessarily be the case if the proponent charges for use (usually to off-set annual maintenance fees); however, these amounts were negligible compared to the other alternatives and would be difficult to estimate because the fees would be based upon usage.

For Modified Combat^{XXI}(Column 7): The proponent estimated a yearly labor cost of approximately $1 million. Based upon development cost information for other models, we estimated another $1 million per year for other development costs, for a total of $2 million per year. The model is currently scheduled to be available in a year; however, we estimate that it

would take at least another year to add in PEO Soldier requirements, for a total of 2 years. Thus, the total expenditure both years is $4 million, half of which would be paid by PEO Soldier. The proponent estimates that annual maintenance costs are $1 million per year, half of which ($500,000) might be paid annually by PEO Soldier.

For Modified IWARS (Column 8): Based upon the IWARS STO request, the total expenditures through FY09 total $10.7 million. We assumed that PEO Soldier would assume 1/3 of the cost (with Natick and AMSAA splitting the remaining 2/3), thus totaling about $3.5 million. The proponent estimates that annual maintenance costs are $1 million per year, 1/3 of which ($333,000) might be paid annually by PEO Soldier.

For Modified OOS (Column 9): The current amount expended under the OneSAF contract is much higher than the other simulations considered, partly because the requirements for that simulation are much broader. Therefore, we used the same costs as that of the next highest software (IWARS) to estimate the costs to PEO Soldier for funding modifications to a small subset of OOS requirements. We used the same annual maintenance costs estimated by the other proponents ($1 million per year), with PEO Soldier responsible for half ($500,000).

For the Combination alternative (Column 10): We summed the amount to modify all three simulations (for a total of $9 million) and divided that number by half based upon the assumption that, by capitalizing on the synergy of the three simulations, PEO Soldier would only have to fund half for each simulation that it would have had to fund if it depended upon only one simulation to meet all of its requirements. We assumed that the maintenance fees of the three simulations would total $1 million for PEO Soldier based upon similar reasoning to the above.

For the New Simulation Alternative (Column 11): We collected available information for the development costs of CASTFOREM, Combat^{XXI}, IWARS, and OOS. Specifically, the total costs estimated by Combat^{XXI}/CASTFOREM developers were $6.5 million (labor only); the costs estimated by IWARS/IUSS developers totaled $13.5 million; and OOS costs so greatly exceeded those of the other two that we did not directly factor them into our estimated development costs. We chose $15 million as a rough estimate for three reasons: 1)

Combat^{XXI}/CASTFOREM included only labor costs, 2) OOS costs reflect a much larger set of modeling requirements than that needed by PEO Soldier, and 3) the new simulation should cost slightly more than IUSS/IWARS, since those models align more closely with PEO Soldier's needs, but require some modification.

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